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FEDERAL EMERGENCY MANAGEMENT AGENCY

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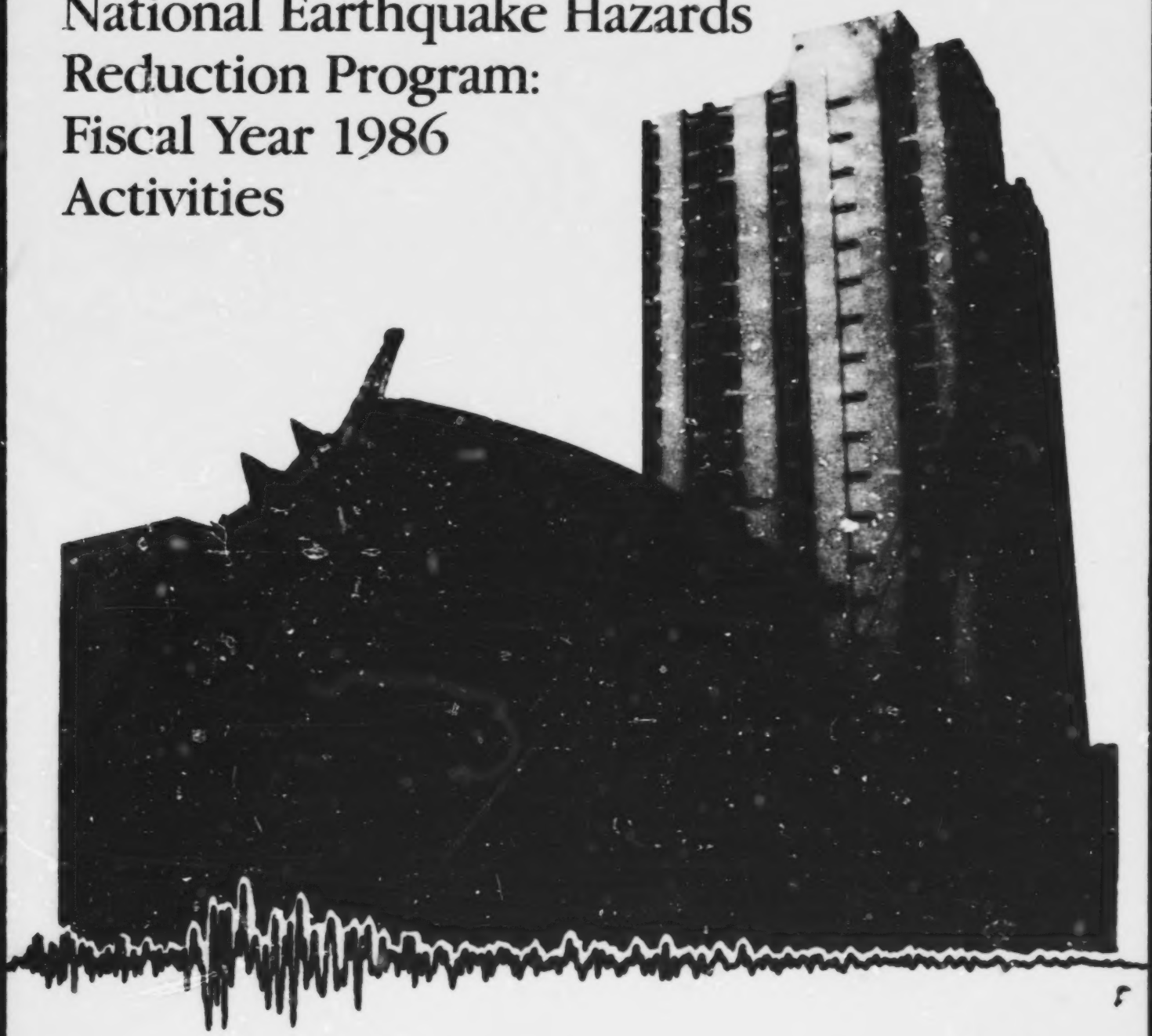
National Earthquake Hazards Reduction Program: Fiscal Year 1986 Activities



Report to the United States Congress

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1985 Mexico earthquake. One of the most spectacular failures was that of the two southern towers in Consumo Pino Suarez. The southernmost 14-story tower collapsed when one of the three 21-story buildings fell on top of it. The 21-story building was one of the few steel-frame structures to collapse during the earthquake.

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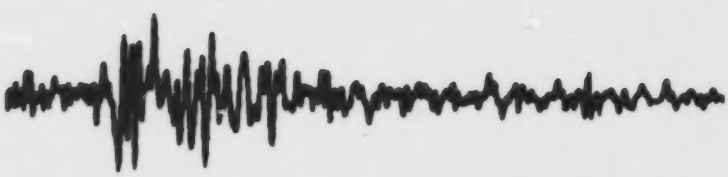
National Earthquake Hazards Reduction Program: Fiscal Year 1986 Activities



Report to the United States Congress

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1985 Mexico earthquake. Search and rescue operations are in progress in the Juarez housing complex. Heavy damage was sustained in these apartment buildings where two 8-story and one 13-story reinforced concrete buildings collapsed.

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PERSPECTIVES

At 7:17 a.m., on September 19,1985, an earthquake of magnitude (M_s) 8.1 struck the western coast of Mexico near Playa Azul in the State of Michoacan. The earthquake caused widespread damage in central Mexico and was felt in El Paso and Houston, Texas. The damage in Mexico City, 250 miles from the epicenter, was severe. Over 8,000 lives were lost as a result of total or partial collapse of more than 500 structures, including schools, hospitals, and apartment buildings. About one hundred thousand people were left homeless. Economic loss was estimated in billions of dollars.

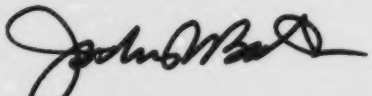
Mexico's experience demonstrates the reality of the consequences of a catastrophic earthquake to lives, property, the economy, and national security. The devastation wrought by the 1985 Mexico earthquake has caused us to reflect on what this Nation could expect from the effects of a major earthquake in any one of several highly populated, high earthquake risk areas of the United States.

When the Congress enacted the Earthquake Hazards Reduction Act of 1977 and established the National Earthquake Hazards Reduction Program (NEHRP), it recognized the need for a comprehensive, integrated national program to reduce losses of life and property resulting from earthquakes. Recognizing that the Mexico earthquake holds vital lessons for the NEHRP, Congress called for special hearings on October 3 and November 5, 1985, to examine the implications of that event.

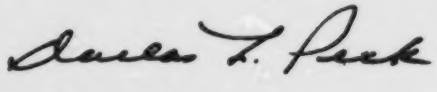
The Mexico earthquake is a major challenge, providing opportunities to gain knowledge and to develop seismic safety practices that will help prevent recurrences of such great losses in the United States. Mexico and the United States share similar construction practices and building types. Structures that performed well and structures that were damaged during the Mexico earthquake provide valuable information for verifying or improving present seismic design codes and standards in the United States.

Mexico City, like many cities in the U.S. that are exposed to severe earthquake hazards, is a large metropolitan community. Detailed review and evaluation of the postearthquake emergency response plans, including damage assessment, health care, search and rescue, and reconstruction, are extremely valuable in developing guidelines for effective response and recovery plans and training programs to minimize the impact of similar disasters in the United States.

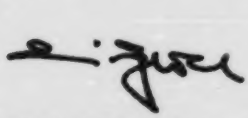
The Federal Emergency Management Agency, the U.S. Geological Survey, the National Science Foundation, and the National Bureau of Standards carry out principal Federal responsibilities for leading, coordinating, and conducting earthquake research, hazard mitigation, and disaster preparedness activities. With the support and cooperation from other Federal agencies, State and local governments, the private sector, and the public, we have made significant progress in reducing the risk to life and property from future earthquakes in the United States. The 1985 Mexico earthquake is a vivid and tragic reminder that much remains to be done.



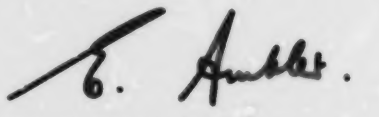
Julius W. Becton, Jr., Director
FEDERAL EMERGENCY MANAGEMENT AGENCY



Dallas L. Peck, Director
U.S. GEOLOGICAL SURVEY



Erich Bloch, Director
NATIONAL SCIENCE FOUNDATION



Ernest Ambler, Director
NATIONAL BUREAU OF STANDARDS

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1985 Mexico earthquake. A common cause of damage occurred when adjacent buildings or portions of buildings hammered against each other. The top portion of a section of this hotel collapsed when hammering occurred at non-structural joints.

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INTRODUCTION

The Report to the Congress on the Fiscal Year 1986 activities of the National Earthquake Hazards Reduction Program (NEHRP) highlights progress made by Federal agencies to achieve NEHRP goals to reduce future loss of life and property from earthquakes and prevent the severe social and economic disruption a catastrophic earthquake could cause. The report is presented in three sections:

- **Principal Agencies:** The Federal Emergency Management Agency, the U.S. Geological Survey, the National Science Foundation, and the National Bureau of Standards provide the basic support and guidance to the NEHRP. These agencies are authorized funds under the Earthquake Hazards Reduction Act of 1977, as amended. In this section, each principal agency provides its account of activities and accomplishments in accord with the elements of the 5-Year Plan for the NEHRP.

NEHRP PROGRAM ELEMENTS AND RESPONSIBLE AGENCIES

Hazards Delineation and Assessment	Regional Monitoring and Earthquake Potential	USGS
	Earthquake Hazards Assessments-National and Regional	
	Postdisaster Mitigation Studies	FEMA
Earthquake Prediction Research	Precursor Evaluation and Prediction Methodology	USGS
	Earthquake Prediction Experiments	
	Theoretical, Laboratory, and Fault Zone Studies	
	Induced Seismicity	
Seismic Design & Engineering Research	Development of Design Practices and Manuals	FEMA/ NBS
	Fundamental and Applied Research	NSF
	Engineering Seismology	USGS
	Modernization of Existing Research Facilities	NSF
	National Earthquake Experimental Facility	FEMA
Preparedness Planning and Hazard Awareness	Earthquake Hazard Mitigation Strategies	FEMA
	Federal Response Planning	
	State and Local Preparedness Planning	
	Multi-Hazard Preparedness Planning	
	Earthquake Education and Information Transfer	
	Societal Response Research	NSF
Fundamental Seismological Studies	Implication of Plate Tectonics	NSF
	The Earthquake Process	
	Earthquake Data and Information Services	USGS

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- **Contributing Agencies:** Federal agencies that contribute to earthquake hazards reduction through related programs, undertaken as part of their basic missions, and participate on interagency committees. This report includes submissions from the Agency for International Development, the Bureau of Reclamation, the Department of Defense, the Department of Energy, the General Services Administration, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the Tennessee Valley Authority, and the Veterans Administration.

- **Interagency Committees:** the Interagency Subcommittee on Federal Response Planning, the Interagency Committee on Seismic Safety in Construction, and the Interagency Committee on Dam Safety.

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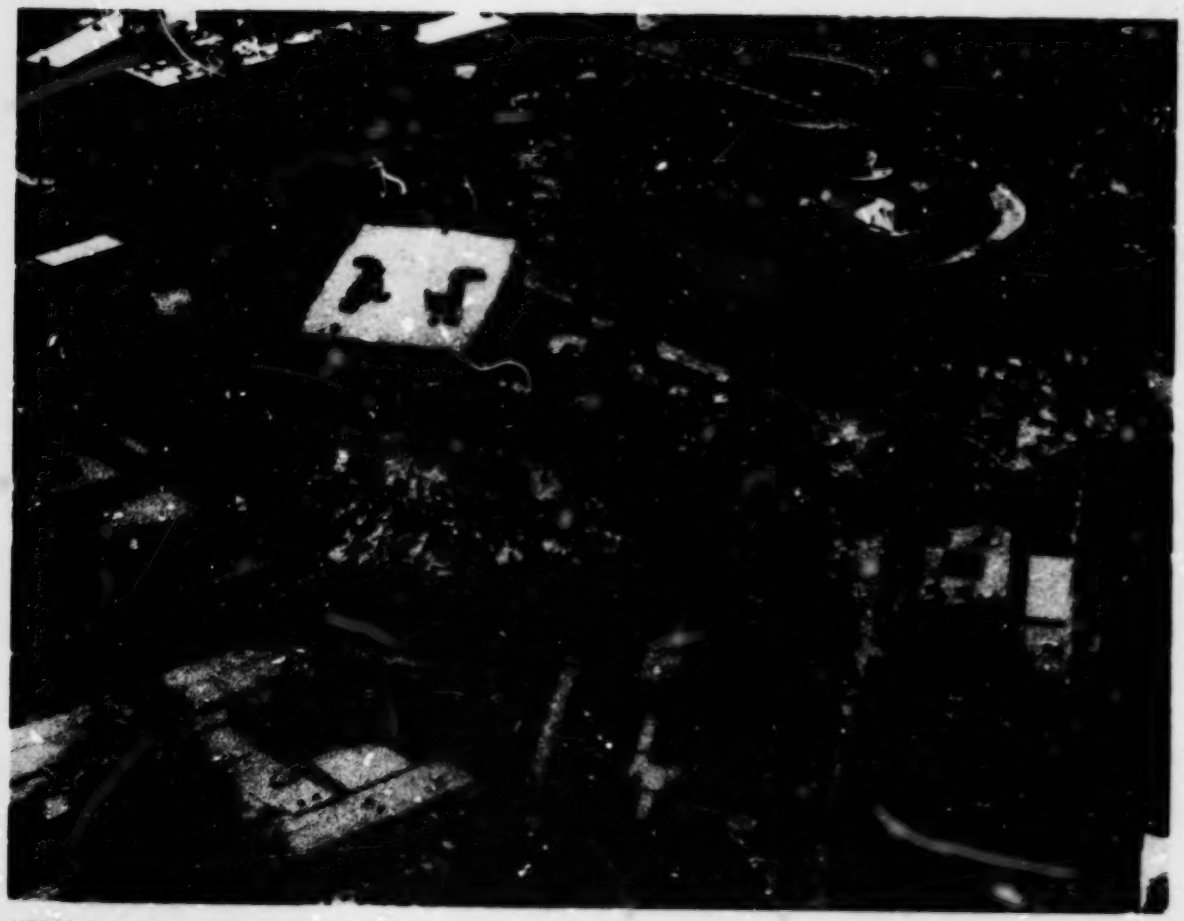

1985 Mexico earthquake. Aerial view of the General Hospital where one 6-story and one 8-story building collapsed.

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FEDERAL EMERGENCY MANAGEMENT AGENCY

As the lead agency for the National Earthquake Hazards Reduction Program (NEHRP), FEMA is responsible for program planning, direction, and coordination, and for stimulation of actions needed to reduce earthquake hazards throughout the Nation. Under its own enabling authorities and in support of the NEHRP, FEMA is also responsible for coordinating Federal emergency management activities for all types of disasters and for providing technical and financial assistance to States and local communities in carrying out their preparedness, response, recovery, and mitigation programs.

LEAD AGENCY ACTIVITIES

In executing FEMA's leadership role in the NEHRP in Fiscal Year 1986, FEMA concentrated on improving program coordination among the principal NEHRP agencies and initiating increased program planning and evaluation activities.

During Fiscal Year 1986, the Interagency Coordination Committee (ICC) of the NEHRP met quarterly to address various technical and operational issues relevant to the NEHRP. Of significance, the ICC representatives from the USGS, NSF, NBS, and FEMA reviewed (1) what lessons can be learned from the Chile and Mexico earthquakes and how those lessons can be assimilated into the NEHRP; (2) the need for and development of a standard loss estimation methodology for earthquakes; (3) the impact of Gramm-Rudman-Hollings on the individual agency programs under the NEHRP; and (4) the progress being made in the various research programs under the NEHRP. The ICC continued its oversight responsibilities relative to the proposed Executive Order on seismic safety in Federal construction and the study on the feasibility of a large-scale testing facility.

Several of the issues discussed by the ICC were referred to the Policy Coordinating Group (PCG) for further review. The PCG, chaired by FEMA, is composed of policy-level representatives of the four principal agencies. During the past year, the PCG convened twice. The first meeting was a thorough briefing on the Chile and Mexico earthquakes and their potential impact on the NEHRP. The second meeting focused on the progress and implications of the balloting on the proposed Executive Order on seismic safety in Federal construction and on the preliminary results of the testing facility study.

In Fiscal Year 1986, FEMA focused its lead agency responsibilities for program planning and evaluation on the requirement to update the NEHRP 5-Year Plan. The 5-Year Plan presents to Congress the programs and activities undertaken by the four principal agencies in support of the NEHRP.

Public Law 99-105, which reauthorized the NEHRP for Fiscal Year 1986 and Fiscal Year 1987, requires that an update of the NEHRP 5-Year Plan be submitted to Congress "at a minimum every three years." This schedule requires FEMA, as lead agency, to submit this revised Plan by September 1988. To meet this deadline, FEMA initiated activities in Fiscal Year 1986 toward revising and updating the Plan. In June, representatives of the four principal agencies met at FEMA's National Emergency Training Center in Emmitsburg, Maryland. They focused on the current status of the NEHRP and on the NEHRP goals and objectives to be included in the revised 5-Year Plan. The meeting led to development of an approach to revision of the Plan which includes establishing a non-Federal Expert Review Committee (ERC). The ERC, composed of nominees from the principal agencies, will provide technical expertise and critical input as the Plan is revised. The members of this Committee represent the broad and diverse spectrum of public and private constituencies of the NEHRP.

In addition, 1987 marks a decade since passage of the Earthquake Hazards Reduction Act. With 10 years having elapsed and approximately $549 million expended, Federal agencies have made significant progress in addressing the Nation's earthquake hazards. In keeping with its lead agency role, FEMA initiated in Fiscal Year 1986 procurement of contractual services for a review of the NEHRP to provide baseline data on the program's performance in that first decade.

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The results of this review, combined with the emerging research and lessons learned from the recent earthquakes, will provide an informational framework for the revised 5-Year Plan. First results of the review are not expected until Spring 1987.

International Coordination

United States/Mexico Earthquake Preparedness Project

Due to the 1985 Mexico Earthquake, the U.S./Mexico Subcommittee on Geological Phenomena postponed its meetings until August 4 and 5, 1986. In the interim, the bilateral working groups met to discuss their tasks.

At the August 1986 meeting in San Diego, the Subcommittee updated the Geological Phenomena Work Plan, with agreement on tasks to be completed over the next 5 months.

The Subcommittee also combined the Local Government and Border Coordination Working Group with the Emergency Planning Working Group; the new group thus formed is the Emergency Planning and Border Coordination and Local Government Working Group.

During the meeting, a presentation was made on the seismic risk in the San Diego area. Following the presentation, the working groups determined to:

- Use the Silver Strand fault for planning purposes;
- Develop a base map with overlays;
- Establish a plan for emergencies in the San Diego-Tijuana area;
- Seek compatibility on bilingual publications; and
- Develop a joint symposium, with participation by the Governors of California and California Baja Norte, on what to do during an earthquake.

The subcommittee agreed to renew for three years the U.S./Mexico agreement on natural disasters.

The next meeting of the Subcommittee was scheduled for January 1987, in Tijuana, and dates were agreed to for future meetings of the working groups.

PRINCIPAL NEHRP ACTIVITIES

FEMA's responsibilities under the 5-Year Plan for the National Earthquake Hazards Reduction Program encompass the following objectives:

- **Hazard Delineation and Assessment.** Post-disaster mitigation studies.
- **Seismic Design and Engineering Research.** Development of design practices and manuals, and evaluation of a national earthquake engineering experimental facility; and
- **Preparedness Planning and Hazard Awareness.** Earthquake hazard mitigation strategies, Federal response planning, State and local preparedness planning, multihazard preparedness planning, and earthquake education and information transfer.

Hazard Delineation and Assessment

Post-Disaster Mitigation Studies

FEMA continued to support, with other agencies, post-disaster studies conducted by the Committee on Natural Disasters of the National Research Council. During Fiscal Year 1986, the major activities of the Committee included post-disaster studies of the Mexico earthquake, the Puerto Rico landslide, and the volcanic eruption in Columbia.

Immediately after the 1985 Mexico Earthquake, the Committee, working with the Earthquake Engineering Research Institute (EERI), dispatched a multidisciplinary team to Mexico. The objectives of the team were to: (1) establish communication with Mexican earthquake researchers and engineers, (2) document perishable information, and (3) make general recommendations for further survey missions and research. Some of the team's findings were presented in Washington, D.C., and in San Francisco, California, with FEMA's sponsorship. Three members of the team also testified in Congressional hearings on the United States' preparedness for such a disaster.

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A preliminary reconnaissance report was jointly published by the Committee and EERI in October 1985 and a final report is in printing. The preliminary report identified eight research areas where lessons can be learned by the United States. The report was one of the major documents used by the Committee on Earthquake Engineering's panel to develop the Joint U.S.-Mexican Research Agenda for the National Science Foundation and other agencies having responsibilities under the National Earthquake Hazards Reduction Act.

Seismic Design and Engineering Research

Development of Design Practices and Manuals for New Buildings

Early in Fiscal Year 1986, the Building Seismic Safety Council (BSSC), under contract to FEMA, approved the 1985 Edition of the *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings*, after a second ballot. Subsequently, an extensive, structured effort was started to disseminate the technology contained in this set of provisions, and to encourage its widespread voluntary use by design professions, the construction industry, building regulatory personnel, and researchers.

A set of complementary publications was also completed. It was designed to encourage use of the *NEHRP Recommended Provisions* by providing a non-technical explanation for the general public and a code-language version for building regulatory personnel and model-code groups. In addition, the handbook on societal implications for community leaders, published the previous year, was expanded and reprinted. These publications are part of FEMA's Earthquake Hazards Reduction Series initiated in Fiscal Year 1985.

The update of the *NEHRP Recommended Provisions*, begun last year and scheduled for completion in 1988, is proceeding as planned. The BSSC Technical Committees have been reconstructed and their memberships updated. Some of them have already begun to consider technical issues left unresolved during the second balloting on the current edition of the Provisions.

Reports prepared by the Building Seismic Safety Council as part of its Program on Improved Seismic Safety Provisions include the following:

NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings, 1985 Edition, 1985.

Handbook for Earthquake Resistant Building Design: Application of the NEHRP Recommended Provisions (1985 Edition), 1986

Guidelines for Preparing Code Changes Based on the NEHRP Recommended Provisions (1985 Edition), 1986

Improving the Seismic Safety of New Buildings: A Non-technical Explanation of the NEHRP Recommended Provisions, 1986

Plan for Stimulating Widespread Use of the NEHRP Recommended Provisions, 1986

Societal Implications: A Community Handbook, Revision 1, 1986

Societal Implications: Selected Readings, 1985

Overview of Phases I and II of the BSSC Program on Improved Seismic Safety Provisions, 1984

Trial Designs, 17 Volumes, 1984

Charleston Designs by Enwright Associates, Inc.,
Chicago Designs by Alfred Benesch and Company,
Chicago Designs by Klein and Hoffman, Inc. (Parts 1-4),
Ft. Worth Designs by Datum/Moore Partnership,
Los Angeles Designs by S.B. Barnes and Associates,
Los Angeles Designs by Johnson and Nielsen Associates,
Los Angeles Designs by Wheeler and Gray,
Memphis Designs by Allen and Hoshall,
Memphis Designs by Ellers, Oakley, Chester and Rike, Inc.,
New York Designs by Weidlinger Associates (Parts 1-2),
New York Designs by Robertson, Fowler, and Associates,
Phoenix Designs by Magadini-Alagia Associates,
Phoenix Designs by Read Jones Christoffersen, Inc.,
Seattle Designs by ABAM Engineers, Inc.,
Seattle Designs by Bruce C. Olsen,
Seattle Designs by Skilling Ward Rogers Bardshire, Inc.,
St. Louis Designs by Theiss Engineers, Inc. (Parts 1-2),

The following materials on existing buildings were developed for FEMA during the ABE Joint Venture (conducted by the Applied Technology Council, Building Seismic Safety Council, and Earthquake Engineering Research Institute):

Proceedings: Workshop on Reducing Seismic Hazards of Existing Buildings, 1985

An Action Plan for Reducing Earthquake Hazards of Existing Buildings, 1985

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Abatement of Seismic Risk Posed by Existing Buildings

At the end of Fiscal Year 1985, ABE Joint Venture completed a 5-year plan to abate the risk posed by existing non-Federal buildings. The Joint Venture partners are the Applied Technology Council, BSSC, and the Earthquake Engineering Research Institute.

During Fiscal Year 1986, FEMA initiated three projects that were among the top priority recommendations of the plan: (1) preparation of a manual to conduct rapid, visual screening of buildings that appear to be potentially seismically hazardous; (2) compilation of typical costs of rehabilitating different types of buildings in areas of different seismicity to make them more earthquake resistant; and (3) preparation of a consensus-backed manual on conducting a qualitative evaluation of those buildings considered to be potentially hazardous as a result of an initial rapid screening. The first two efforts will be completed in about 18 months, and the third, in about 36 months.

Study of Lifeline Systems

Toward the end of Fiscal Year 1985, FEMA issued a contract with the BSSC for the preparation of a 5-year plan on lifeline systems. In scope and objectives, the plan is similar to the one dealing with existing hazardous buildings. Development of the lifeline systems plan is on schedule and should be completed by spring 1987. The plan will provide guidance on actions to take in Fiscal Year 1988 and beyond to lessen the impact of earthquakes on lifeline systems.

Evaluating Dissemination of Seismic Design Information

A private contractor has completed for FEMA the development of a methodology to evaluate in future years the extent of dissemination and diffusion throughout the construction industry of the technology embodied in the *NEHRP Recommended Provisions* and its complementary materials.

The approach is to survey major professional societies, owners' groups, and public interest groups. Various survey instruments and evaluation techniques could be used, and the contractor has provided approximate cost and confidence-level estimates relative to surveying alternative respondent groups.

If funding is available, FEMA will initiate an evaluation utilizing this methodology in Fiscal Year 1987.

National Earthquake Engineering Experimental Facility

FEMA, NBS, and NSF, recently joined by the USGS, are well into the first phase of the interagency feasibility study that will, when completed, provide the basis for a decision whether or not to construct a national earthquake engineering experimental facility. The full- or nearly full-scale structural behavior information obtained from such a facility would improve seismic-resistant design and construction.

The National Research Council's Advisory Panel to the study released a letter report in 1986 containing a number of general and specific recommendations for enhancing the study's benefits to researchers, the engineering profession, the public, industry, and government. The National Research Council's Committee on Earthquake Engineering is distributing copies of the letter report. Among the recommendations included in the report are:

- Extend the first phase, which deals with user and research needs. This phase was initially planned to take one year to produce a 3- to 5-year experimental program with facility requirements. The panel felt that the study is so important to the future direction of earthquake research and experimental testing that it should be approached with diligence and care.
- Broaden the study perspective with respect to research/experimental facility needs to include the alternatives of a centralized versus decentralized approach, and alternatives in testing methods (e.g., smaller shake tables, reactions walls, etc.). The Panel cautioned against focusing on one large test facility although, from a technical/scientific

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point of view, the benefits from a large shaking table were recognized.

- Adopt an international approach to include assessment of experimental facilities abroad, future plans of other countries, and opportunities for the United States to become a world leader and major participant in selected experimental capabilities. The Panel feels that the international market aspect may become much more important as we approach the 21st Century—when large experimental facilities might be completed.
- Explore potential sources of additional funding for the feasibility study, including other government agencies and private organizations and industries.
- Establish priorities for research/experimental facility needs so that potential new funds will be spent wisely.

Preparedness Planning and Hazard Awareness

Earthquake Hazard Mitigation Strategies

Fiscal Year 1986 marked progress for earthquake hazards reduction in the areas of State planning initiatives, national training efforts, and Federal policy for seismic design standards for new or substantially improved Federal facilities.

As part of an agreement with FEMA arising from previous disaster assistance, Idaho produced a hazard mitigation plan intended to address problems of earthquake vulnerability throughout the State. Utah, as part of a similar commitment to FEMA stemming from earlier flood disaster relief, developed a comprehensive, multihazard mitigation plan including a well-defined program for reducing earthquake hazards statewide.

In Fiscal Year 1986, FEMA undertook a number of training and education efforts for the benefit of Federal, State, and local planners and mitigation officers typically involved in post-flood disaster mitigation. These efforts featured extensive exercises designed to: (1) increase awareness of earthquake hazards; (2) provide knowledge on technical assistance resources for mitigating seismic hazards; and (3) stimulate a multihazard approach for pursuit of mitigation.

Executive Order: Federal Construction Activities

At the request of FEMA, the Interagency Committee on Seismic Safety in Construction (ICSSC) has been developing a draft Executive Order intended "to reduce risks to the lives of occupants of Federal buildings and to persons who would be affected by the failures of Federal buildings or lifelines in earthquakes, to improve the capability of Federal buildings and lifelines to function during or after an earthquake and to reduce earthquake losses of public property, all in a cost effective manner."

The draft Order covers new and existing buildings and lifeline systems, and federally leased, assisted or regulated buildings and lifeline systems. If the Order is promulgated, new Federal buildings would have to be designed to nationally accepted seismic standards; for lifeline systems and for leased, assisted or regulated buildings, the draft Order would require Federal agencies within a 3-year period to establish procedures and adopt standards suited to their own mission needs.

Under the proposed Order, the ICSSC would be responsible for developing procedures and standards, using a consensus approach; in its annual report to the Congress, FEMA would assess the success of the Order's implementation.

The draft Order has been balloted twice by the ICSSC member agencies, and remaining differences were resolved by the end of Fiscal Year 1986. The draft Order is expected to be ready for submission to the Office of Management and Budget in Fiscal Year 1987.

Earthquake Loss Estimation Methods Study

The National Academy of Sciences (NAS), through the Committee on Earthquake Engineering, began a study to provide FEMA with recommendations on comprehensive earthquake loss-estimation methods. Such methods would be used by State and local governments in earthquake preparedness and mitigation planning. It is expected that the

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methods recommended will be generally applicable throughout the United States; some variation may be appropriate, however, due to variations in regional seismic conditions and construction practices, particularly east of the Rockies. The methods to be reviewed include primarily those developed by the USGS, FEMA, and the Applied Technology Council, as well as any other promising methods identified. The study will evaluate both comprehensive estimation methods and rapid, approximate techniques for pre- and post-disaster loss estimation.

The needs of user agencies are important in choosing loss estimation methods, and considerable effort is being made to identify the users and their specific loss-estimation information needs. As part of that effort, a workshop is being held early in the project to involve both the users and producers of earthquake loss-estimation methods.

The Committee on Earthquake Engineering has formed a special panel to conduct the study. The panel includes nationally recognized experts in public policy, political science, economics, urban planning, geology, seismology, earthquake engineering, and architecture. The final report will also identify directions for further research, development, and testing of the recommended methods to enhance credibility and relevance to user needs.

Banking and Insurance Institutions

The joint NSF-FEMA grant to a consortium of insurance and banking firms resulted in a set of guidelines for producers and users of large data processing facilities and systems. Other vulnerable systems that were identified include utilities, telecommunications, and check-sorting equipment. Guidelines for these were still in preparation by the end of the Fiscal Year. Also in preparation at that time was a discussion of earthquake contingency planning actions that should be taken by banking and other financial institutions.

The effort is scheduled to conclude by the end of Calendar Year 1986 with publication of a report, and convening of several workshops to disseminate the results of the study.

Federal Response Planning

The Federal Government, working through the Subcommittee on Federal Earthquake Response Planning, has developed a Final Proposed National Plan for Federal Response to a Catastrophic Earthquake. The Plan represents the collective efforts of 25 Federal and voluntary departments and agencies, all of which have been assigned responsibilities in the Plan.

During Fiscal Year 1986, the Subcommittee incorporated the lessons learned from RESPONSE 85 (a joint interactive exercise held during June 1985) into the Final Proposed National Plan. Aspects of the Plan have also been developed as a result of lessons learned from response operations after the earthquake in Mexico in September 1985. The Plan was published in the Federal Register on June 30, 1986. Publication in the Federal Register marked a milestone of significantly increased Federal Government preparedness to respond to a major earthquake in any of the identified high-risk, high-population seismic areas.

The National Plan is based on the fundamental assumption that a catastrophic earthquake will overwhelm the capability of State and local governments to carry out the extensive emergency operations necessary to save lives and protect property. Consequently, resources and authorities of Federal departments and agencies have been grouped into broad categories of response activities—called emergency support functions—to provide Federal assistance. Primary and support agency responsibilities have been identified for each of these functions.

Under the Disaster Relief Act of 1974 (Public Law 93-288), as amended, a Federal Coordinating Officer (FCO) will be appointed as the President's representative to coordinate overall delivery of Federal assistance. Federal officials will be designated for each department and agency to carry out the provisions of the Plan, and will be responsive to the overall management and direction of the FCO.

Comments received during the Federal Register comment period were taken into consideration in revising the National Plan. The Final National

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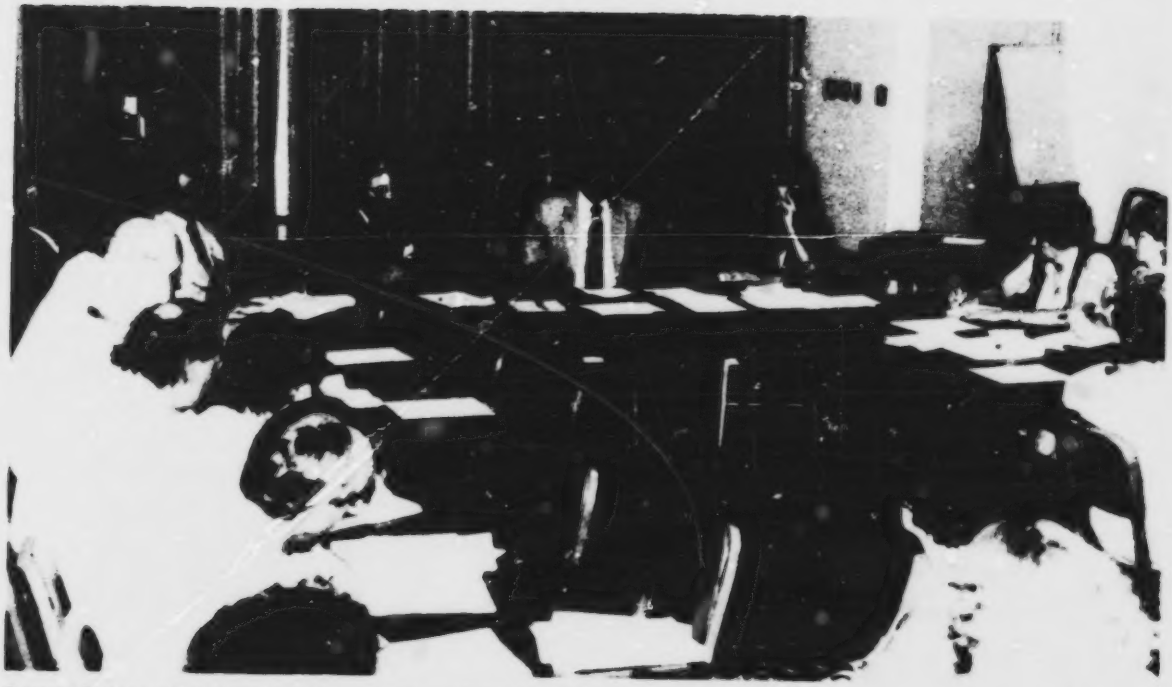

General Becton addressing the Subcommittee on Federal Earthquake Response Planning.

Subcommittee on Federal Earthquake Response Planning at work.

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Plan will be signed by the 25 participating department and agency heads. Those signatures will signify agency commitment to develop and maintain the supplemental and regional planning that must be done to establish a coordinated Federal response structure.

State and Local Preparedness Planning

In Fiscal Year 1986, FEMA supported earthquake preparedness planning activities in 12 areas of high population and high earthquake risk. These areas are at various stages of progress in implementing their earthquake hazards reduction programs. A brief description of their activities and accomplishments during Fiscal Year 1986 is provided below.

Southern California Earthquake Preparedness Project (SCEPP)

SCEPP was established in September 1980, as a result of national and State level concerns over the threat to southern California of an expected but unpredicted 8.3 magnitude earthquake along the southern San Andreas Fault. The State was judged essentially unprepared to cope with the resulting disruption of transportation, communications, medical care, business and industry, and the economy. Provision of basic services, and housing and community environments would also be disrupted. SCEPP has been jointly funded by the State of California and FEMA, and functions under the authority of the Governor's Office of Emergency Services. Its overall goal is to stimulate comprehensive earthquake preparedness within its jurisdiction of Los Angeles, Orange, Riverside, San Bernardino, and Ventura Counties. To achieve this goal, SCEPP conducts activities in the following major areas:

- Planning Assistance Efforts. SCEPP planning assistance with Orange County resulted in a multiyear hazard mitigation plan. A similar effort has begun with Los Angeles County. Through these planning assistance programs, preparedness plans are now being completed in the most heavily populated areas of southern California. Ninety percent of the population will receive earthquake preparedness materials through local jurisdictional planning by the end of Fiscal Year 1987. As part of planning assistance activities, SCEPP has begun to provide guidance on the application of the FEMA Essential Building Survey results for development of hazard reduction programs at the local level.

- Earthquake Preparedness Information and Education. SCEPP has participated actively in organizing and supporting the annual California Earthquake Preparedness Week and Campaign. It has provided the framework for development of outreach programs for business, neighborhood, and school earthquake preparedness information and education programs.

  Through the Information Network and Referral System (INRS), SCEPP has begun to develop links to resource centers in southern and northern California.

  The INRS now links the American Red Cross, the Bay Area Regional Earthquake Preparedness Project (BAREPP) and SCEPP by computer to maintain resource files on earthquake preparedness, planning and engineering documents, reports and referral systems.

  Through the SCEPP School Earthquake Task Force, school administrators in southern California are now more aware of their responsibilities and liabilities regarding earthquake and emergency planning. SCEPP has assisted with the distribution of FEMA's *Guidebook for Developing a School Earthquake Safety Program* in southern California.

  SCEPP has now prepared unique and useful materials for initiation of neighborhood self-help campaigns at the local level. These programs emphasize coordination and effective use of community volunteers at the time of an earthquake.

- Regional Earthquake Preparedness Planning. SCEPP initiated its most ambitious planning effort by developing much-needed regional emergency management systems to be employed during a catastrophic earthquake in southern California. This is a multiyear effort and the first of its kind in the nation. Regional emergency planning includes development of

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regional emergency management systems for transportation, mass care, public information, and medical care.

- Earthquake Prediction Response. SCEPP has played an important role in policy and plan development for the State of California response to the Parkfield earthquake prediction experiment. SCEPP has worked closely with the U.S. Geological Survey, FEMA, State agencies, and affected local governments to plan for a predicted earthquake in southern California. The plans and policies developed for the Parkfield prediction will be used for State-wide prediction planning.
- Technical Assistance. SCEPP has provided essential technical information for reducing structural earthquake hazards by sponsoring and conducting a seminar for local building officials and structural engineers. The seminar, entitled "The Hazardous Buildings Ordinance: A Key to Earthquake Safety and Economic Recovery," will be of vital support to the new California State law which mandates local government inventories of hazardous buildings and development of hazard mitigation plans.
- Local Incentive Grant Program. SCEPP supported innovative, local government-initiated earthquake preparedness programs by providing direct grants to local jurisdictions including school districts, counties, and city police, fire, and planning departments.

San Francisco Bay Area

The Bay Area Regional Earthquake Preparedness Project (BAREPP) completed its second year of operation as a project of the California Seismic Safety Commission, supported by matching funds from FEMA and the State of California. A major focus of the Project continues to be that of providing planning and technical assistance to a wide range of public and private sector entities. This planning and assistance is related to hazard mitigation, preparedness, response, and recovery. Activities this year have been directed toward distributing existing materials, and the development of topic-specific workshop training materials. This was accomplished through a regional conference covering BAREPP's 10-county planning area and a series of subregional workshops. These were attended by over 1,000 participants from local government, business and industry, utilities, hospitals, schools, volunteer and community groups, and the media, who have responsibilities and functions related to earthquake preparedness planning. In addition BAREPP:

- Participated in the organization of the State-wide Earthquake Preparedness Week, developed and disseminated materials to be used by public and private sector organizations, and assisted Bay Area media in providing coverage of earthquake week activities;
- Sponsored a workshop for local media representatives to support the development of a coordinated earthquake response plan to encourage greater involvement of the media in providing preparedness information both before and after an earthquake;
- Co-sponsored a school earthquake preparedness conference for public and private school officials, administrators, and teachers, to disseminate information on all aspects of school safety planning. This conference included an introduction to FEMA's *Guidebook for Developing a School Earthquake Safety Program*, which has been distributed to all K-12 schools in California by the Seismic Safety Commission;
- Developed a videotape on how to identify and mitigate nonstructural hazards in schools;
- Developed a checklist of nonstructural hazards to be used by public and private organizations to assess their non-structural hazard risk;
- Developed a videotape entitled "How Earthquakes Affect Buildings" to provide basic education on how the structural elements of four types of buildings perform in earthquakes;
- Developed a dual projector slide/tape program entitled "Making a Difference Using Earth Science Information," which provides information on how to mitigate seismic risk through sound land use decisions based on the effective use of earth science information. The program provides case study documentation;
- Developed curricula, with supporting audio-visual and handout materials for half-day workshops on six special topics:

  Earthquakes and the Threat to High Rise Buildings

  Special Problems Posed by Hazardous Materials in Earthquakes

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Earthquake Hazard Mitigation Programs at the Community Level

Better Use of Earth Science Information

Hospitals and Earthquakes

Conducting a Hazardous Building Survey

- Developed strategies for using existing local and regional networks to address multi-jurisdictional earthquake preparedness, response, and recovery issues;
- Provided intensive planning and technical assistance, developed hazard vulnerability maps for local government planning partners, and responded to requests for assistance from many other jurisdictions and private sector interests;
- Developed checklists (including earthquake preparedness, mitigation, response, and recovery actions) for local government, business and industry, media, hospitals, schools, neighborhoods, and Bay Area decision makers;
- Published *NETWORKS: Earthquake Preparedness News*, including a Special Issue on "Lessons for the Bay Area from the Mexico City Earthquake of September 19, 1985," which has been distributed to approximately 8,000;
- Maintained and expanded the BAREPP Resource Center, which includes a database of earthquake information resources, and a library of research publications, public information, and audio-visual resources available for loan or duplication by public and private sector groups;
- Developed, through the Local Incentive Grant Program initiated last year, innovative approaches and materials to achieve earthquake preparedness in community groups, private businesses, and schools;
- Awarded four additional grants for the coming year.

Washington

Last year, a successful effort was mounted through the State legislature to establish a State Seismic Safety Commission. The bill was vetoed by the Governor, who believed that the objectives of the Commission could be accomplished under existing law and administrative arrangements. He directed the Department of Emergency Management (DEM) to implement a program which would meet the intent of the vetoed bill. During Fiscal Year 1986, the Director of DEM appointed a Seismic Safety Council—a multidisciplinary body similar to that of the Commission envisioned in the vetoed bill.

The council received excellent support from the scientific community, governmental officials, and others interested in earthquake hazard mitigation. The Council's goal for Fiscal Year 1986 was to produce a set of recommendations to the Governor and the legislature establishing an earthquake hazard reduction program for the State of Washington. By the end of the fiscal year, the Council adopted a set of proposals involving earthquake hazard mitigation and earthquake education.

A school earthquake education and preparedness program was implemented in Fiscal Year 1986; it had been under development during the preceding 2 years. For the first time, the program was extended beyond the Seattle City Schools; workshops were held for educators in other school districts in Washington and British Columbia. Continuing work with the Seattle City Schools has aimed at institutionalizing the earthquake education and preparedness program that had begun as a pilot project. One indicator of success is the agreement by the Seattle City Schools to provide matching funds for an earthquake education program in Fiscal Year 1987.

Also in Fiscal Year 1986, the Federal Earthquake Response Plan for the Puget Sound Area was updated, and a series of meetings was held to educate Federal officials in use of the Plan.

Alaska

In Fiscal Year 1986, the Alaska Division of Emergency Services began a 2-year program to examine and upgrade the earthquake safety of buildings owned and leased by the State government. The first year was devoted to identifying State facilities, setting priorities among the facilities relative to importance of earthquake emergency response, and examining State building standards. The program is concerned with the earthquake resistance of structures and the vulnerability of equipment, furniture, and supplies. The intent of the program is to reduce the risk of

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earthquake death or injury to State personnel, to insure that the State government can respond adequately to an earthquake, and to set the example for local governments and private industry.

In response to a warning from the State Seismologist about the increased probability of a great earthquake in the Shumagin Gap area, the Division of Emergency Services held meetings with village leaders throughout the Aleutian chain, the Alaska Peninsula, and Kodiak Island to upgrade earthquake and tsumani response preparedness. The tsunami preparedness activities this year—and of the previous 3 years—paid off on May 7 of this year when a 7.7 magnitude earthquake triggered a tsunami warning and generated a tsunami. Evacuations and other emergency activities proceeded smoothly in accordance with the State and local plans. The tsunami was not great enough to cause serious damage.

The City of Anchorage completed the major components of a risk assessment program. The city can now provide an expected earthquake loss estimate, in terms of dollars and lives, for every parcel of land in Anchorage under current or proposed land uses. Public hearings have been started to develop a consensus on the acceptable level of earthquake risk. The objective of the program is to provide a data base which will lead to more rational land use decisions. The Alaska Division of Emergency Services will use the program to assess the site vulnerability of its buildings.

The Federal Earthquake Response Plan was reviewed, especially with reference to its effectiveness in last year's earthquake exercise. Federal agencies were generally pleased with the plan.

Hawaii

Initial studies funded by FEMA concluded that an earthquake of sufficient magnitude to cause destruction and loss of life could occur along the Diamond Head Fault on the Molokai Seismic Zone. Such an earthquake would affect the densely populated, high-rise building areas of downtown Honolulu and Waikiki.

The studies highlighted the need for earthquake plans and mitigation strategies. In 1983, the Earthquake Response Planning guide for the State of Hawaii was published. Today, FEMA, State civil defense planners, and planners for the City and County of Honolulu, are coordinating efforts to develop the plans and activities necessary to a viable earthquake preparedness program. Specific initiatives in Fiscal Year 1986 were:

- Continued development and refinement of the State of Hawaii Earthquake Preparedness Plan;
- Formal partnership between the State of Hawaii and the City and County of Honolulu to develop county earthquake response plans, standard operating procedures, exercises and checklists to respond to a major earthquake in the metropolitan Honolulu area; and
- Continued development and conduct of a viable State-County oriented earthquake program emphasizing joint planning sessions, exercises, seminars, public awareness campaigns, and private sector coordination.

Utah

Major Fiscal Year 1986 activities included:

- Funding the response planning efforts of the Utah Geological & Mineral Survey (UGMS). These efforts were initiated because the UGMS will play a significant role in the post-earthquake environment. That role will need to be planned and integrated with the overall response plan of the State and the Utah Division of Comprehensive Emergency Management;
- Public awareness and education activities for specific target audiences in the Wasatch Front area, including awareness packets, workshops, and conferences;
- Continued negotiation of mutual aid agreements among the Utah counties most heavily impacted by a Wasatch Front event, and with surrounding U.S. Army facilities and divisions.

Central United States

The Central United States Earthquake Preparedness Project (CUSEPP) addresses the earthquake threat in a multistate area of the Central Mississippi Valley (Arkansas, Illinois, Indiana, Kentucky, Mississippi, Missouri, and Tennessee). CUSEPP is an integrated effort of

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In 1986, public and private sector officials participated in the Memphis/Shelby County (TN) disaster preparedness exercise based on an earthquake scenario.

State-specific and multistate activities seeking to enhance preparedness and implement mitigation measures for the identified multistate earthquake hazard area of the New Madrid Seismic Zone. Major Fiscal Year 1986 activities included:

- Continued support to the Central U.S. Earthquake Consortium (CUSEC). CUSEC was formed by the seven States to provide a forum for addressing the interstate aspects that are inherent in the implementation of CUSEPP. Funded initially by FEMA in April 1984, CUSEC is a 5-year developmental effort which provides the seven States with the mechanisms and coordination needed to reduce earthquake hazards on a broad, multistate basis;
- Initiation of *pro bono publico* legal services for the research and development of a multistate document enabling interstate response to an earthquake event in the central United States;
- Deployment of a computerized response resources management system in the seven States, which will allow a coordinated multistate response, as well as enhanced individual State response capabilities;
- Release to the area's media of a set of public service announcements to increase the public's awareness and to provide knowledge about preparedness measures; and
- Continued support to each of the seven State's individual efforts, allowing State-specific public awareness and school education campaigns, the development and testing of response plans at local and State levels, and the utilization of State specialists in various earthquake-related fields to identify long-range earthquake hazard reduction needs and tasks.

South Caroline

The State continued the vulnerability study for the Charleston area, including Berkeley and

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Representatives of the seven States comprising CUSEC received hands-on training on the response resources management system.

Dorchester counties. The study, scheduled to be completed by the end of calendar year 1986, will assess the earthquake hazard and serve as the basis for the development of mitigation strategies and response planning. In Fiscal Year 1986, the State initiated the development of a multiyear seismic safety plan and cosponsored with the Earthquake Education Center at Charleston an earthquake education workshop for State and local officials. Other workshops were held in cooperation with the South Carolina Seismic Safety Consortium (SCSSC) on the role of the public and private sectors in earthquake preparedness and the impact of earthquakes on lifelines. The SCSSC recently gained official status through incorporation.

Massachusetts

Massachusetts continued the vulnerability study for the Boston metropolitan area. The study is based on a repeat of the Cape Ann Earthquake of 1755. Massachusetts also pioneered the sponsorship of the New England Governor's Council for the New England Seismic Advisory Council, officially established to coordinate regional activities concerning earthquake preparedness planning. Earthquake education and awareness activities in Fiscal Year 1986 centered on a workshop on the earthquake hazards in the region.

New York

New York continued its earthquake hazards reduction program with the identification of four seismic zones for the State. A vulnerability study was initiated for Clinton County. The study will assess the performance of critical facilities in the county in responding to an earthquake with an intensity of VII on the Modified Mercalli Scale.

Virgin Islands

The Virgin Islands initiated the development

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of a comprehensive earthquake emergency plan that will be incorporated into the "Virgin Islands Emergency Operations and Disaster Control Plan." Also intitiated during the fiscal year were activities to mitigate the effects of damaging earthquakes.

Puerto Rico

Puerto Rico continued its vulnerability study of the San Juan metropolitan area by conducting an analysis of the susceptibility of critical structures to damaging earthquakes. This study will be the basis for the development of mitigation strategies to further reduce the effects of earthquakes, particularly in the design, construction, and renovation areas. The metropolitan areas of Ponce and Arecibo had economic vulnerability analyses performed similar to the one for San Juan.

An education program was initiated to make the public aware of earthquake hazards and ways to mitigate losses. This was partially achieved with the third workshop on earthquakes, held in San Juan.

Multihazard Preparedness Planning

All seismically hazardous areas are also prone to other disasters. For areas where earthquake recurrence periods are long and current seismic activity is low, earthquake preparedness measures may be politically and economically feasible only if combined with measures to reduce other hazards. The capability to respond to multiple disaster agents becomes especially critical when events such as fires, dam failures, landslides, and toxic spills are triggered by an earthquake.

Multiple Hazard Risk Assessment Methods

Work is continuing on the FEMA and NSF cooperative research effort to develop a systematic, rational strategy for local governments to use in assessing risk from multiple hazards. State and local governments under FEMA's Integrated Emergency Management System (IEMS) are required to assess these risks, set priorities, and prepare multihazard mitigation and preparedness plans. Little guidance is available to these governments as to which methods can be used and how to integrate the hazard/risk findings with their public policy.

Interviews with experienced local governmental risk managers have been conducted during the last year by members of the study team experienced in assessing local governmental risk management decision-making processes. A workshop will be held during which risk and public policy experts and community risk managers and officials will identify scientifically sound and politically practical risk assessment methods. The final research report is expected in 1987.

Utah Model Multihazard Planning Process

In 1976, the USGS completed an earthquake vulnerability study for Utah that showed a potential for a severe earthquake in that State, especially along the Wasatch Front. About 85 to 90 percent of the State population is within the risk area.

One issue of particular concern has been the possibility of seismically induced dam failures. The 1976 report projected that the loss of life from the floods resulting from earthquake induced dam failures could far exceed the loss of life caused by the seismic event itself—23,000 versus 2,300, respectively.

In 1982, the State of Utah, with support from FEMA, began a multihazard mitigation pilot program to enhance the State's ability to respond to the potential for dam failures and other natural hazards. The State was to develop a mitigation and preparedness model responsive to the potential hazards; field tests would evaluate the model, its application, and results.

The model was developed and field tested in Ogden City/Weber County. Specific mitigation strategies were identified and adopted by the city and county leaders. Clearly, mitigation is not something that will occur overnight, and the local officials have recommended a multiyear plan to accomplish the program goals. Subsequently, other city and county leaders expressed interest in the model approach and have begun prototypical mitigation planning in the Provo area.

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The project was evaluated by FEMA and a non-governmental reviewer; it was given high marks. It will be reviewed periodically to determine the success of the long term implementation of the mitigation strategies, and to measure the savings attributable to the mitigation activities. FEMA continues to evaluate the project and its results to determine how to tailor the model for transfer to other State and local governments.

Landslide Hazard Mitigation Plan

Landslides are a collateral geologic hazard associated with earthquakes and often are a significant component of multihazard disasters. As a followup to the work of the Committee on Ground Failure Hazards Mitigation Research of the National Research Council, FEMA is starting to develop a prototype State landslide hazard mitigation plan and a guidebook to assist other States' development of such a plan. The prototype mitigation plan will address the landslide hazard and its relationship to the earthquake, flood, and dam safety hazards. It is expected that the prototype plan can be integrated with existing State hazard mitigation plans and will provide technical assistance to local governments. The guidebook will be comprehensive, capable of national transfer, and applicable to the unique needs of every State.

The prototype landslide hazard mitigation plan will be prepared chiefly by the State of Colorado's Division of Disaster Emergency Services and Geological Survey, working with FEMA and the USGS. The plan will be oriented toward traditional State-local governmental responsibilities and roles.

The guidebook is expected to assist other States in preparing similar plans, and will introduce the practical aspects of planning and plan implementation. Colorado will communicate with all other States with significant landslide hazard mitigation programs for information to develop the content of the prototype plan and guidance materials. Content selection will be based on the recommendations of an advisory panel consisting of representatives of other States' emergency managers, environmental planning and budget offices, State geological surveys, geotechnical engineering organizations, and local governments.

Earthquake Education and Information Transfer

A highlight of FEMA's Earthquake Education Program was the publication of the *Guidebook for Developing a School Earthquake Safety Program*. This product is the result of a multiyear developmental and field test effort that involved the participation of specialists in school administration, education, psychology, earth science, engineering, fire safety, and emergency management. The Guidebook is designed to help school personnel and students improve their capability to respond safely and effectively in the event of a damaging earthquake. It contains checklists and suggestions for identifying earthquake hazards in classrooms and along building evacuation routes; conducting earthquake drills; preparing response, communication, and shelter plans; and initiating training programs to improve staff skills in fire abatement, first aid, and search and rescue.

Within 1 month of its release in February 1986, the California Seismic Safety Commission directed the distribution of copies to all public and private schools in that State. By the end of the fiscal year, FEMA had responded to hundreds of requests for over 25,000 copies from State and local emergency services offices and schools in 28 States, Canada, Mexico, and New Zealand.

Community Outreach Projects

In Fiscal Year 1986, FEMA continued to manage the Public Information Challenge Grants Program to stimulate the development of effective public information strategies at the State and local levels. Products received from grantees during the fiscal year include:

- Eastern Kentucky University (Richmond, KY) completed five 30-second television public service announcements (PSA's), five 30-second radio PSA's, and three newspaper articles containing safety information designed to increase awareness of earthquake risk and preparedness in the Central U.S.
- Davis County (Utah) developed two 20-minute videotapes for use by community leaders to promote neighborhood planning and preparedness.
- The Valley Women's Club of San Lorenzo Valley (CA) developed a model neighborhood organization plan with emphasis on

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Richard Hackett, Mayor of Memphis, announces proclamation of Earthquake Safety Week

household preparedness, community resource assessment, and communications. In addition, accompanying materials were developed to teach other communities how to set up neighborhood disaster networks.

August 1986 marked the end of the third and final year of FEMA's direct support of the Earthquake Education Center (EEC) in Charleston (SC) and the EEC in Memphis (TN). During this past year, both Centers noted a continued increase in requests for information about regional earthquake risks and for assistance in developing earthquake safety programs for schools, hospitals, government agencies, and businesses.

During the first three quarters of its third year, the EEC in Memphis provided 249 presentations, directly reaching 12,000 individuals. An additional 7,873 were reached through the project's exhibit at the Mid-South Fair. During that same period, the EEC in Charleston reached 8,146 people through 116 presentations, and conducted two half-day workshops for media representatives and a 2-day workshop for South Carolina emergency preparedness coordinators representing 36 of the 46 counties in that State.

Both EEC's were active in promoting community-wide activities. The Memphis center organized the second annual Earthquake Safety Week in February. With help from the Tenn-Ark-Miss Girl Scout Council and with financial support from three insurance companies, hundreds of safety posters were distributed to schools and shopping centers. Local TV stations provided earthquake safety tips at the end of their weather reports and distributed over 2,000 copies of brochures to interested citizens. City and county schools participated by entering the EEC's poster and essay contests.

The Charleston EEC also held a poster contest, which involved the participation of 40

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Jennifer Hayslip teaches sixth graders about earthquakes at Collierville Middle School in Memphis.

Third grade finalist in South Carolina poster art contest.

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schools in the tri-county area. That effort and the EEC's publication of a booklet on "Low Country Quake Tales," were among several activities carried out by this Center in preparation for the commemoration of the 1886 Charleston Earthquake and South Carolina's first statewide Earthquake Safety Week.

In February 1986, FEMA awarded funds for the evaluation of the two EEC's and the previously supported pilot school earthquake safety and education project in Seattle, Washington. The purpose of this ongoing study is to obtain an overview of the projects' implementation processes and the relative success of their various activities in accomplishing their outreach objectives. The study will result in the preparation of general guidance for conducting outreach educational programs for schools and other community groups based on the lessons learned through these pilot projects.

Multihazard Education Project

The Children's Television Workshop (CTW), supported by a FEMA grant, has undertaken a major project to develop a program to teach children and their families about natural hazards.

Following the successful process developed for the FEMA Sesame Street Fire Safety Project, CTW initiated the first phase of the natural hazards project in Fiscal Year 1985. That phase involved research to find out what children know about natural hazards, the level of safety information they can absorb, and approaches to help them deal with emergencies. The results of this research became available in Fiscal Year 1986, and formed the basis for subsequent efforts to develop strategies and messages to present information about natural hazards to various age groups.

Training Activities

During Fiscal Year 1986, FEMA piloted a new course, "Nonstructural Earthquake Hazards Mitigation for Hospitals" at Memphis, TN, and at the Emergency Management Institute (EMI) in Emmitsburg, MD. This course addresses the unique problems confronting hospitals in the event of a damaging earthquake. It focuses on practical ways to reduce risk to the facility and its population, and provides practical recommendations for developing or improving earthquake contingency response plans.

EMI also offered an integrated emergency management course on earthquake response for local emergency managers and the course, "Earthquake Hazard Mitigation for Utility Lifeline Systems," designed for public works directors and engineers.

Third U.S. National Conference on Earthquake Engineering

With FEMA financial support the Earthquake Engineering Research Institute (EERI) conducted the Third U.S. National Conference on Earthquake Engineering in Charleston, SC, on the 100th anniversary of the 1886 Charleston Earthquake. This was the first national conference to be held since the one in 1979 in California, and the first such conference to be held on the east coast.

The Conference made a significant contribution to the transfer of state-of-the-art technology and information dissemination. Conference topics included faulting and tectonics, geotectonics, retrofitting of existing structures, emergency preparedness planning, and hazard mitigation measures. Conference activities included a town meeting, an educational campaign involving elementary through college students in a variety of contests, and an exhibit of photographs and publications documenting events of the Charleston Earthquake of 1886.

Western States Seismic Policy Council (WSSPC)

The Annual Meeting of the WSSPC was hosted by the Oregon State Emergency Management Division, October 22-23, 1985 in Portland, Oregon. The agenda was highlighted by presentations on the 1985 Mexico Earthquake. WSSPC members from the California Seismic Safety Commission and the California Office of Emergency Services

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reported on their observations and meetings with representatives of the Mexican Government.

National Bureau of Standards (NBS) personnel who were part of the post-disaster assessment teams provided an overview of the structural damage that resulted from the quake.

Other meeting highlights were presentations on the successful public-private ventures of the Earthquake Preparedness Week in California, the Governor's Workshop on Earthquake Hazards held in Wyoming, the National Disaster Medical System, and restoration of historical buildings for seismic resistance. The meeting concluded with transfer of the chairmanship of the WSSPC from the State of Oregon to the State of Wyoming for 1986.

American Institute of Architects (AIA) Workshop

FEMA joined NSF in sponsoring a workshop convened by the AIA Foundation in Seattle, Washington, October 25-26, 1985. This was the third such workshop in a continuing series designed to provide architects and related building professionals the information necessary to engage in earthquake-resistant design.

The workshop focused on (1) developing a comprehensive understanding of the risk and nature of earthquakes that threaten the Nation's Pacific Coast; (2) sharing state-of-the-art seismic design techniques; and (3) application of the recently completed *NEHRP Recommended Provisions*. Over 100 people participated in this workshop.

OTHER ACTIVITIES

Emergency Information and Coordination Center

Within FEMA, the Emergency Information and Coordination Center (EICC) serves as the focal point for day-to-day monitoring operations along with the Alternate Emergency Information and Coordination Center (AEICC). Information collected during emergency situations flows into the EICC/AEICC on a 24-hour basis from FEMA Headquarters and from the field, as well as other agencies—public and non-profit—involved in the emergency management community at the National, State, and local levels. In turn, that information is disseminated to specific emergency managers who must make disaster-related decisions.

Disaster Assistance

One of FEMA's most visible forms of assistance occurs when the President declares an emergency or major disaster under the provisions of the Disaster Relief Act of 1974, Public Law 93-228. Such a declaration is made when the situation is of such severity and magnitude that effective response is beyond the capabilities of local and State efforts and resources, and Federal assistance is necessary. The Governor of the affected State may request the President to make such a declaration and submit his request to FEMA's Regional Director. FEMA then evaluates the impact of the disaster, determines the requirements for supplemental Federal assistance, and makes a recommendation to the President.

Direct Federal disaster assistance falls into two broad categories: public assistance (aid to State and local governments) and individual assistance (aid for disaster victims and their families). Mitigation efforts are also carried out under disaster assistance programs to help ensure the future safety of lives and property.

FEMA is responsible for coordinating the disaster assistance provided by all other Federal agencies. To make it easier for people to obtain disaster assistance, FEMA establishes one or more Disaster Application Centers in the affected area. These centers provide a central location where representatives of Federal agencies, State and local governments, and voluntary relief agencies can offer aid to disaster victims. Such assistance may include temporary housing, low-interest disaster loans, and grants to individuals and families to assist in meeting their needs. During Fiscal Year 1986, no Presidential disaster declarations were made due to an earthquake event.

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U.S. GEOLOGICAL SURVEY

The USGS Earthquake Hazards Reduction Program supports fundamental and applied research in earthquake hazards and earthquake prediction to provide earth science data and information essential to reduce risks to life and property from future earthquakes in the United States. The program fosters hazard reduction through land-use planning, earthquake-resistant design, and emergency preparedness. The USGS program is a principal part of the National Eathquake Hazards Reduction Program, and includes the major efforts of the Federal Government in earthquake-related studies in seismology, geology, and geophysics, as well as important efforts in soils engineering.

The USGS program is focused on objectives of four of the five elements of the National Earthquake Hazards Reduction Program 5-Year Plan:

HAZARD DELINEATION AND ASSESSMENT

Regional Monitoring and Earthquake Potential Studies

- Monitor and evaluate the earthquake potential of seismically active areas of the United States.

National and Regional Earthquake Hazards Assessments

- Provide evaluations of earthquake hazards and risk in earthquake-prone regions.

EARTHQUAKE PREDICTION RESEARCH

- Conduct research to establish the capability to predict the size, location, and time of damaging earthquakes.

SEISMIC DESIGN AND ENGINEERING RESEARCH

Engineering Seismology

- Provide strong ground motion data to the engineering community for use in earthquake-resistant design and construction and conduct research to understand the physics of ground motion.

FUNDAMENTAL SEISMOLOGICAL STUDIES

Data and Information Services

- Provide data and information on earthquake occurrences to the public, scientific community, and other governmental agencies.

The USGS participates in foreign earthquake investigations and a number of international cooperative projects in observational seismology, studies of strong ground motion, and earthquake prediction to accelerate and enhance earthquake research in the United States. The USGS also conducts an active outreach program to transfer earthquake hazards information to the public and user communities. The USGS Earthquake Hazards Reduction Program is augmented and strengthened through support of complementary scientific investigations in universities, State agencies, and private companies.

HAZARD DELINEATION AND ASSESSMENT

Regional Monitoring and Earthquake Potential Studies

The USGS makes seismological and geologic analyses of seismic activity, active geologic faults, and earthquake potential of seismic regions in the United States. These studies are designed to:

- Delineate seismically active areas and the extent of seismic zones with regional seismograph networks;
- Determine the geometry and structure of seismic zones through geologic mapping and geophysical analyses; and, ultimately,
- Estimate fault slip rates, maximum earthquakes, and recurrence intervals for active faults and seismogenic zones.

Scientific data collected from regional monitoring and earthquake potential studies form the foundation for work in earthquake prediction

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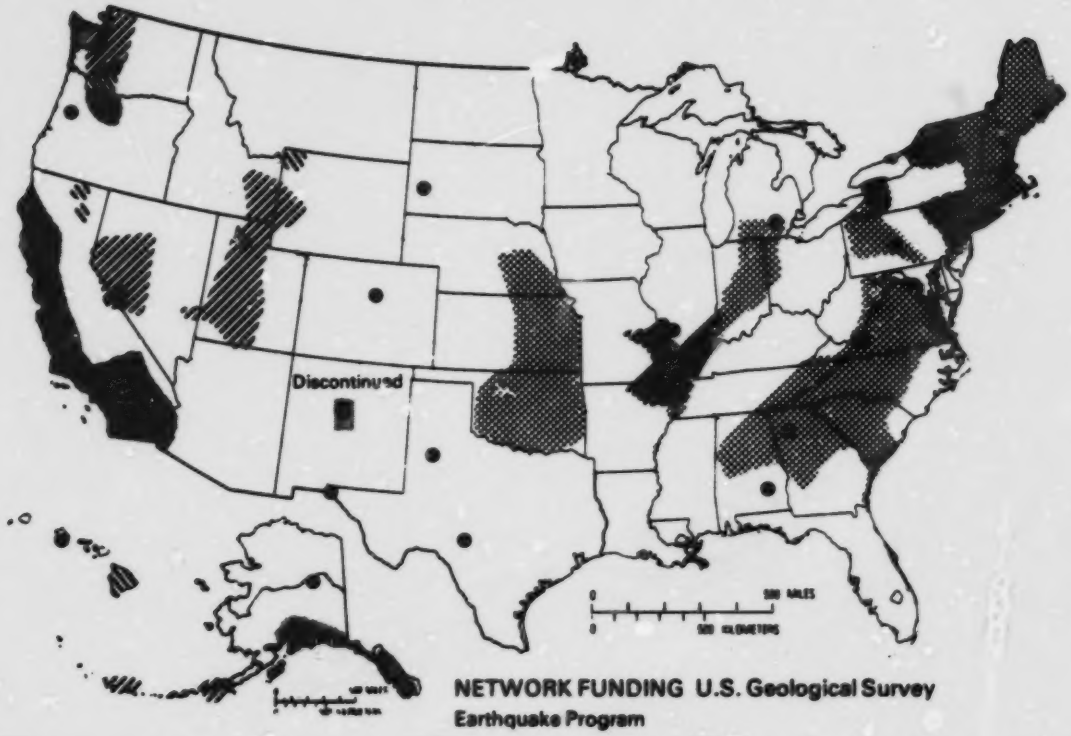

Regional seismograph networks supported by the USGS and the Nuclear Regulatory Commission. The USGS operates or supports 22 regional seismograph networks, located primarily in the Western United States. The Nuclear Regulatory Commission finances operation of four regional seismograph networks (composed of 15 local networks) in the Eastern United States. The two agencies jointly support networks in the Central United States and the Northeast. Stations of the USGS Global Seismographic Network monitor earthquake activity worldwide.

and regional earthquake hazards assessments. Detailed geological and geophysical investigations of seismically active areas of the United States have identified numerous active faults, many previously unknown, and other tectonic structures. Studies of the slip rates and earthquake histories of several faults have permitted long-term forecasts of earthquake recurrence.

Regional Seismograph Networks

The USGS supports operation of 22 regional seismograph networks to monitor seismically active and volcanic areas of the Nation. The networks are located principally in the Western United States (including Alaska and Hawaii), as well as in areas of the Eastern United States, Puerto Rico, and the U.S. Virgin Islands. These networks of closely spaced, highly sensitive seismographic stations permit high-resolution determination of the location, depth, size, and mechanism of small- to moderate-size earthquakes. The networks provide important baseline data for earthquake prediction and hazards assessments and contribute directly to the understanding of earthquakes and tectonic processes that cause earthquakes through:

- Prompt location of earthquake events.
- Observation of changes in microearthquake activity that may be premonitory to large, potentially damaging earthquakes.
- Delineation of active faults and seismic zones.
- Investigation of the structure of the Earth's crust and upper mantle.

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USGS REGIONAL SEISMOGRAPH NETWORKS

Regional seismograph networks supported by the USGS Earthquake Hazards Reduction Program:

USGS-operated networks:

- Northern and central California
- Southern California
- Southern Alaska
- Western Washington (Olympic Peninsula)
- Socorro, New Mexico (*discontinued in fiscal year 1986*)

University-operated networks (funded with extramural grants from the USGS Earthquake Hazards Reduction Program):

Southern California	California Institute of Technology
Los Angeles Basin, California	University of Southern California
Anza (San Jacinto/Borrego Valleys), California	University of California, San Diego
Central Aleutian Islands, Alaska	University of Colorado
Shumagin Islands, Alaska	Columbia University, Lamont-Doherty Geological Observatory
Washington (Puget Sound/Cascades)	University of Washington
Nevada	University of Nevada, Reno
New Madrid, Missouri	St. Louis University
New York	Columbia University, Lamont-Doherty Geological Observatory
Southern Intermountain	University of Utah

Regional seismograph networks supported by the USGS Volcano Hazards Program:

USGS-operated networks:

- Hawaii (Hawaiian Volcano Observatory)
- Washington Cascades (Mount Rainier to Mount St. Helens)
- Long Valley caldera (Mammoth Lakes), California
- Mount Shasta, California
- Mount Lassen, California

University-operated networks (funded by the USGS Volcano Hazards Program):

Yellowstone National Park, Wyoming	University of Utah

Regional seismograph networks supported by the USGS Geothermal Investigations Program (both operated by the USGS):

- Oregon Cascades (Mount Hood to Three Sisters)
- The Geysers, California

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Several of the USGS regional seismograph networks are operated by USGS personnel. Most of the networks are operated by universities and afiliated research groups. The networks are financed chiefly by the Earthquake Hazards Reduction Program. Networks located in volcanic areas are supported by the Volcano Hazards and Geothermal Investigations Programs.

Painesville, Ohio, Earthquake

Northeastern Ohio and a large area of the surrounding Eastern United States and Canada were shaken Monday morning at 11:46 a.m. EST, January 31, 1986, by a moderate-size earthquake of magnitude 4.9 to 5.0. The earthquake was the largest in northeast Ohio since at least the mid-1850's. The earthquake occurred about 25 miles east of Cleveland, near Painesville, Ohio. The earthquake caused local damage and widespread panic in Painesville and Mentor, Ohio, prompting the temporary evacuation of several public buildings. The earthquake was felt over a broad area including 11 States, the District of Columbia, and parts of the province of Ontario, Canada.

The rare incidence of earthquakes in Ohio and the proximity of the shock to the Perry Nuclear Power Plant (the earthquake was located about 11 miles south of the nuclear facility) triggered a rapid response by seismologists from the USGS and at least six other agencies, universities, and institutions. Networks of some 47 portable seismographs, including analog and broadband, wide-dynamic-range digital instruments, were deployed in 64 sites in the epicentral region beginning only 10 hours after the mainshock. Geological field teams were dispatched to search for surface faulting and secondary ground failures, including landslides and liquefaction, that might have been generated by the earthquake. Two intensity surveys to document the violence of the earthquake motion were also begun immediately following the mainshock.

The most severe damage (Modified Mercalli intensity VI) was found within 9 miles of the instrumental epicenter. Damage consisted primarily of wall cracks, cracked or fallen plaster (generally in older buildings), fallen ceiling tiles, damaged chimneys, disturbed wells, items fallen off shelves, broken pipe seals and cracked windows. No surface faulting or significant ground failure, however, was discovered.

No aftershocks were detected in the first 26 hours and only 13 were reported by April 15, 1986. Most of the early aftershocks occurred at a depth of 3 to 4 miles within a very small source volume less than 1 mile in diameter. Analysis of the mainshock and aftershocks indicates no obvious structure or fault with which the January 31 earthquake can be associated. The focal mechanism of the mainshock suggests that either right-slip or left-slip occurred on a nearly vertical fault plane. Locations of aftershocks are permissive of the interpretation of a fault striking somewhat east of north, but as most of the aftershocks are tightly clustered in space, they provide only very weak evidence for the orientation of such a structure.

The proximity of the January 31, 1986, earthquake to several deep (6,000 feet) waste disposal wells near Perry, Ohio, prompted an assessment of the degree to which the deep fluid injection may have influenced the recent earthquake activity. Estimates of stress inferred from commerical hydrofracturing measurements suggest that the state of stress in northeastern Ohio is close to the theoretical threshold for small earthquakes (as predicted by the Mohr-Coulomb failure criterion). Given this state of stress, triggering of small earthquakes by fluid injection would not be surprising. The probability that the injection played a significant role in triggering the earthquake, based on the information currently available, must be regarded as low. Several observations argue for a tectonic origin for the earthquake:

- The distance of the January 31 earthquake and its aftershocks from the wells (with the exception of a very small earthquake on March 12).

  The mainshock of the January 31 earthquake and all of its immediate aftershocks occurred more than 10 miles from the injection wells near Perry, Ohio.

- The lack of any small earthquakes detected near the bottom of the Perry injection wells.

  In the best-documented cases of injection-induced seismicity, small earthquakes

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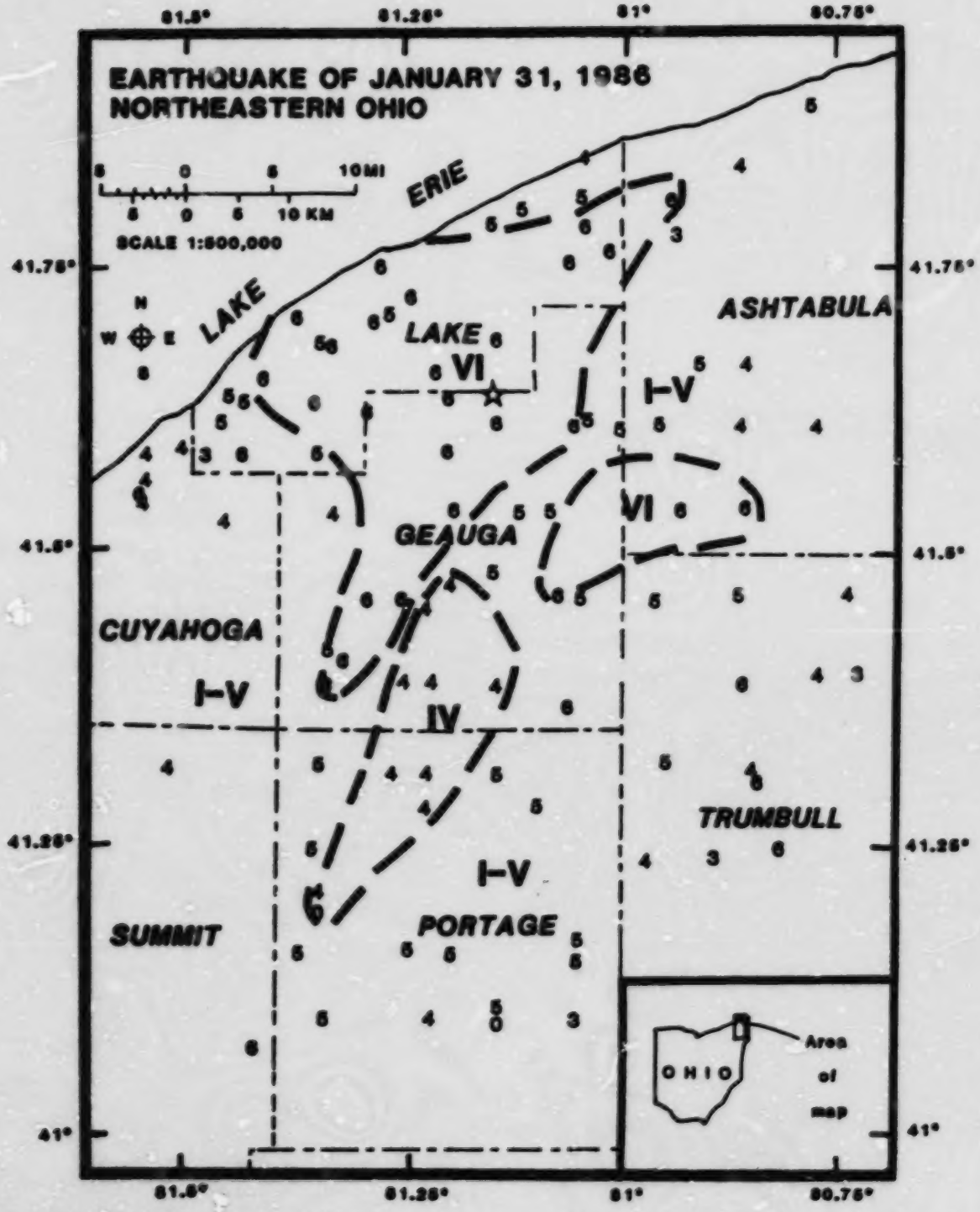

Preliminary isoseismal map of the Painesville, Ohio, earthquake of January 31, 1986. Site intensities are shown by Arabic numerals; isoseismal intensities are denoted by Roman numerals. The mainshock epicenter is located with a star.

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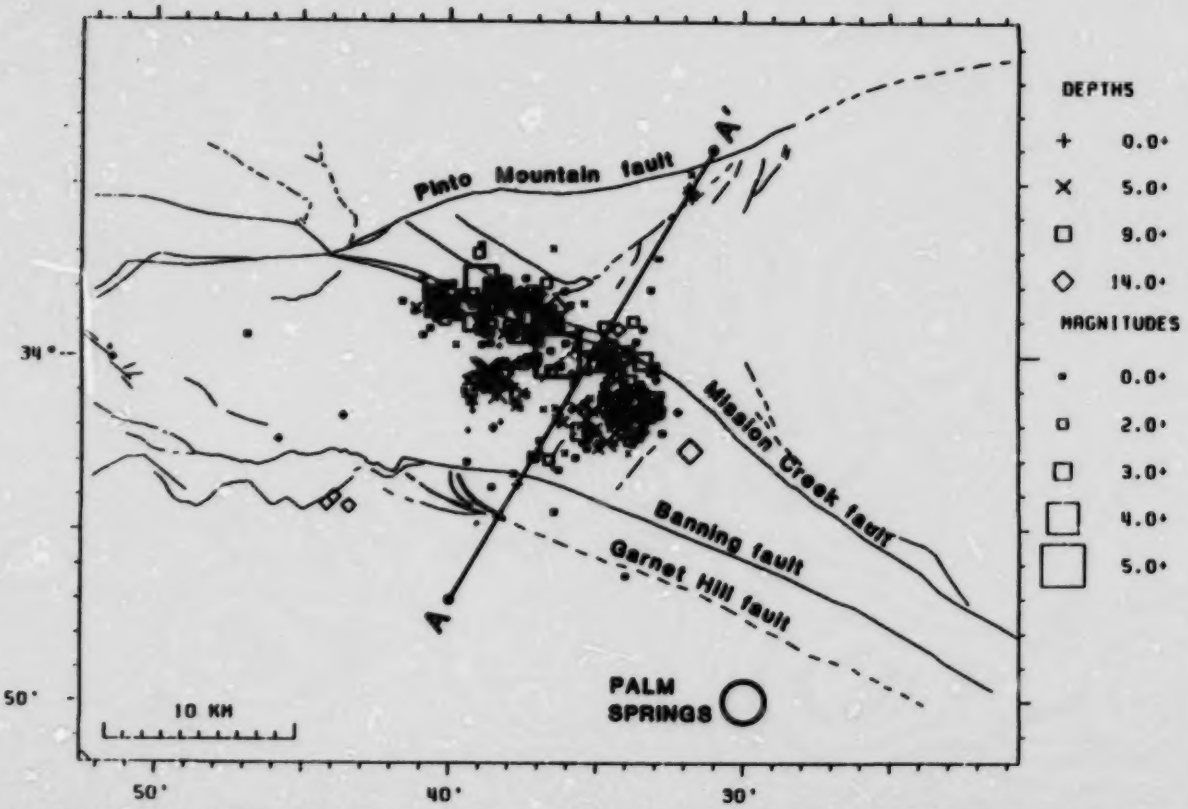

Epicentral locations of the mainshock and location aftershocks of the July 8, 1986, Palm Springs earthquake. The mainshock occurred at a depth of 7 miles.

began near the bottom of the injection wells and then migrated outward.

- The history of small to moderate earthquakes in the region prior to the initiation of injection.

  At least 30 felt earthquakes in the northeastern region of the State have occurred during the last approximate 100 years. The largest event known prior to 1986 was a magnitude 4.5 to 4.7 earthquake in 1943. The 1943 earthquake occurred just slightly west of the 1986 event.

- The attenuation of the pressure field with distance from the injection wells.

Palm Springs, California, Earthquake

A moderate, magnitude 5.9 earthquake occurred at 2:21 a.m. PDT, Tuesday, July 8, 1986, near Palm Springs, California. The earthquake was centered on the southern San Andreas fault zone about 8 miles northwest of Palm Springs, at the north end of the Coachella Valley. The earthquake was felt widely throughout southern California and as far east as Las Vegas, Nevada. The shaking triggered numerous rock falls and rock slides in the San Bernardino and San Jacinto Mountains, closing several roads near Palm Springs and initiating forest fires in the Cabazon (San Gorgonio Pass) area. The shaking also caused moderate damage in the Palm Springs area; power service to about 80,000 people was interrupted. In Cathedral City, 5 miles southeast of Palm Springs, the shaking caused a fire that damaged a glass company.

The earthquake was detected and quickly located by the southern California regional seismographic network, operated jointly by the USGS and the California Institute of Technology. At daybreak, teams of USGS geologists discovered surface faulting in the epicentral area along both the Banning and Mission Creek branches of the southern San Andreas fault

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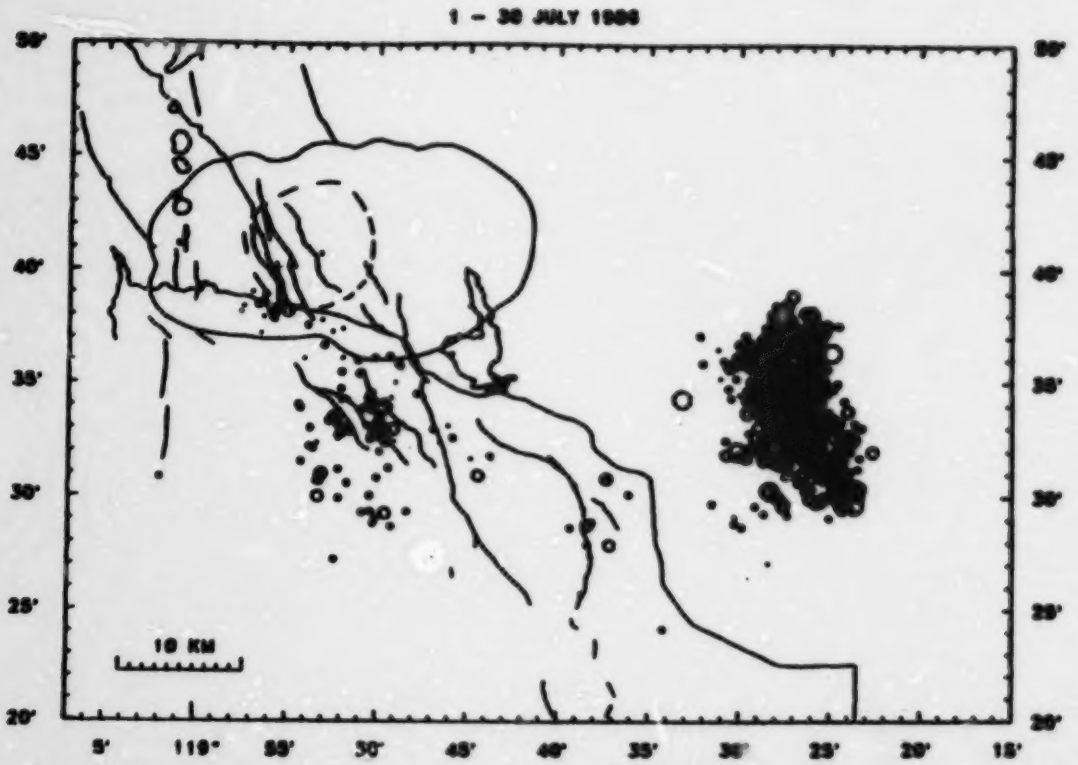

Aftershocks of the 1986 Chalfant Valley, California, earthquake were located southeast of Long Valley caldera in an irregular, northwest-trending area roughly 16 miles long and 6 miles wide. The shocks occurred at depths of 1 to 9 miles on a fault plane dipping roughly 50° W.

zone. A line of breaks nearly 2 miles in length was found on the Banning fault near North Palm Springs. As much as 3 inches of right-lateral movement was measured on the fault in the broken pavement of California Highway 62. Cracks were also discovered in the highway several miles to the north where California 62 crosses the Mission Creek fault. The observed offset is consistent with the mechanism for the July 8 earthquake, which indicates that right-lateral movement occurred along a fault striking N. 60° W. and dipping north at 45°.

Chalfant Valley, California, Earthquake

The eastern Sierra Nevada were shaken at 7:42 a.m. PDT Monday, July 21, 1986, by a moderately strong earthquake near the California-Nevada border. The magnitude 6.0 to 6.2 earthquake was centered in the Chalfant Valley, about 16 miles north of Bishop, California. The earthquake was felt strongly throughout central California and parts of western Nevada. House trailers in the village of Chalfant were thrown from their supports; minor damage was reported in Bishop.

The earthquake occurred about 5 miles north-northwest of Chalfant, at a depth of approximately 8 miles. A vigorous aftershock sequence followed, with more than 30 events of magnitude 4 and several thousand smaller earthquakes recorded in the first nine days following the July 21 mainshock. The aftershock sequence included a magnitude 5.4 shock and a 5.1 shock at 7:51 a.m. and 3:10 p.m. PDT, respectively, on Monday, July 21.

The earthquake apparently was caused by movement on the White Mountains fault at the east side of Chalfant Valley. USGS geologists discovered minor surface rupture along a 1.9 mile-long section of the fault in the epicentral are. As much as 1.6 inches of right-lateral

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offset was measured on a series of left-stepping fractures in the fault break. The geologists also found evidence for distributed east-west extension, with fresh extensional cracking on many of the north-striking faults that cross the volcanic tablelands west of Chalfant Valley. Early results from remeasurement of the trilateration network that spans the epicentral region confirm westerly extension of as much as 6.7 inches. The surface rupture and trilateration data are roughly consistent with the preliminary mainshock focal mechanism, which indicates that oblique right-lateral slip occurred on a fault plane dipping 60° W. and striking N. 25° W.

The July 21 earthquake had been preceded by a prolonged foreshock sequence that began with a magnitude 2.6 earthquake at 12:42 a.m. PDT on July 3 located approximately 4 miles west-northwest of Chalfant. Magnitude 1 to 2 events continued to occur sporadically in the same general area over the next 2 weeks. The sequence escalated at 9:00 a.m. on Friday, July 18, with a magnitude 4 event in the same general area; a magnitude 5.5 event followed at 7:29 a.m. PDT on Sunday, July 20. Each of these events produced progressively stronger aftershock sequences.

The building earthquake sequence prompted USGS Director Dallas L. Peck on July 21, 1986, to write William M. Medigovich, Director of the California Office of Emergency Services, calling his attention to the Chalfant Valley earthquake sequence. Peck advised that, based on the behavior of other earthquake sequences in the area, additional magnitude 6 earthquakes might occur in the next several days. (In May 1980, three magnitude 6 earthquakes occurred during one day about 25 miles west of Chalfant in Long Valley caldera; a fourth magnitude 6 earthquake followed just two days later.) The Director pointed out that the July 21, 1986, earthquake occurred at the southern end of the White Mountains seismic gap, an area recognized as having the capability of generating a magnitude 7 earthquake. In 1984, USGS scientists warned that recent clusters of moderate earthquakes, including the four magnitude 6 earthquakes in Long Valley in May 1980, had partially encircled the White Mountains seismic gap, raising concern over the likelihood of a major gap-filling earthquake within the coming years to decades. On July 24, 1986, the Director sent a second letter to Medigovich indicating that, because the aftershocks of the magnitude 6 earthquake of July 21 appeared to be decaying in a normal manner, the concern over the likelihood of additional magnitude 6 events within the coming days to weeks had diminished and would continue to diminish as long as no abrupt changes in either the rate of seismic activity or its location were observed.

The July 1986 earthquake sequence was another in a succession of significant episodes of seismic activity that have occurred in the Long Valley region at roughly 18-month intervals since 1978. The activity began on October 4, 1978, with a magnitude 5.7 earthquake just south of Long Valley near Wheeler Crest, California. The earthquake was followed less than two years later by the sequence of four magnitude 6 earthquakes in Long Valley on May 25 to 27, 1980. A magnitude 5.7 earthquake was recorded south of Long Valley on September 30, 1981. In January 1983, an intense swarm of several thousand earthquakes occurred in the south moat of Long Valley caldera. On November 23, 1984, a magnitude 5.7 earthquake occurred in Round Valley, at the foot of Wheeler Crest. The Chalfant Valley event falls within the 95 percent confidence interval for this linear recurrence trend.

Potential Great Earthquakes in the Pacific Northwest

The subduction, or underthrusting of great crustal plates beneath continental margins typically is accompanied by the repeated occurrence of very large shallow earthquakes. Along the coastline of the Pacific Northwest, the Juan de Fuca and Gorda plates are being thrust under North America. The plates are converging with western Washington, Oregon, and northern California at a rate of about 1.3 to 1.6 inches per year. Despite the continuous monitoring of this region with a local seismometer network since 1970, very few earthquakes of any size have been observed in the coastal regions of Washington and Oregon. Most puzzling of all, there have not been any historic low-angle thrust earthquakes between the continental and subducted plates. The two simplest interpretations of these observations are: (1) the Cascadia Subduction zone is completely decoupled (unattached) from North America

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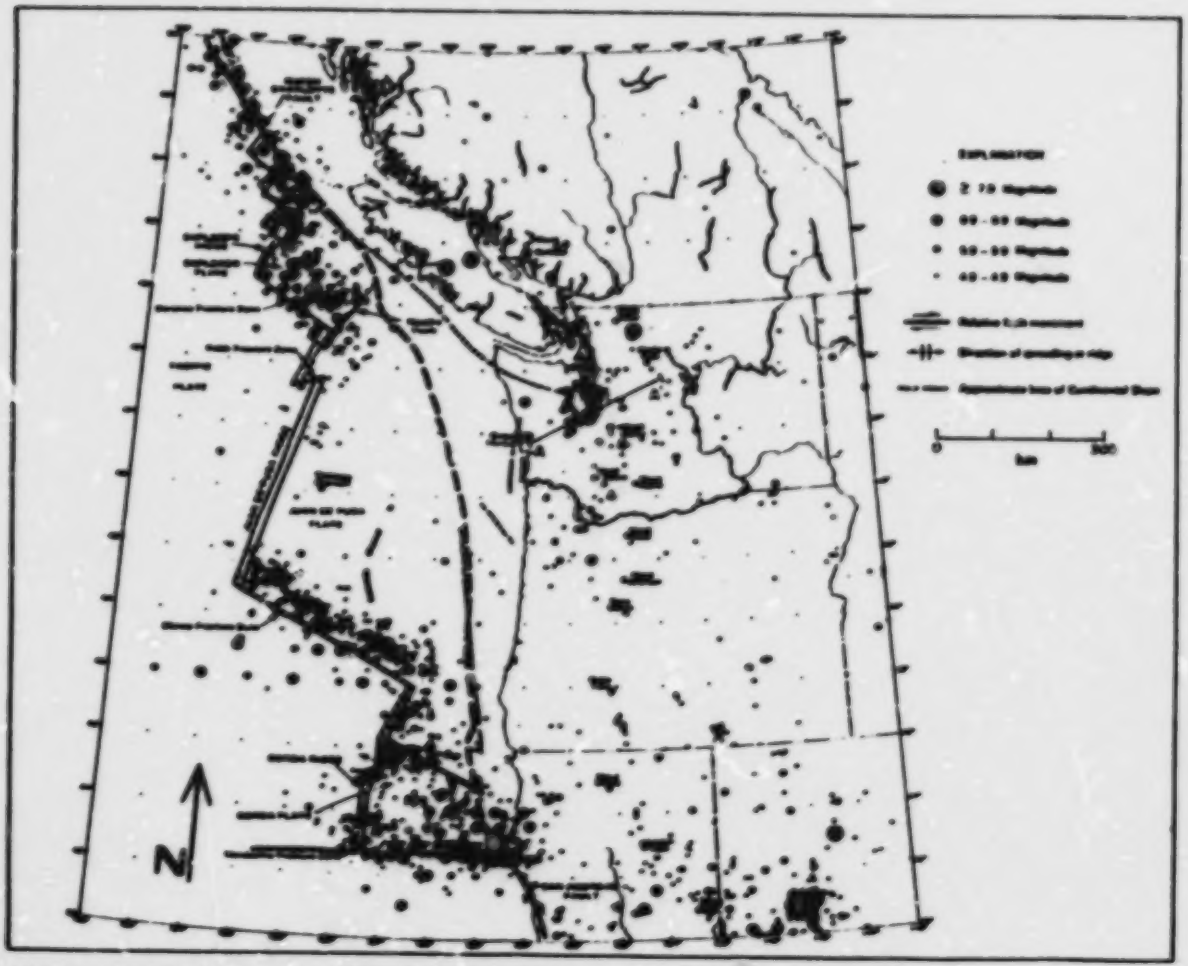

Major crustal plates and associated seismicity of the Pacific Northwest. The Northwestern United States may be a major seismic gap which is locked and presently seismically quiet but which may fail in great earthquakes in the future.

and subduction is occurring aseismically, or (2) the Cascadia subduction zone is locked and storing elastic energy to be released in future great earthquakes.

A growing body of data suggests that the plates are locked, and that compressive strains are building between the converging plates. Analyses of geodolite surveys in the Seattle, Washington, region from 1972 to 1984 and triangulation surveys in the Seattle, Washington, region from 1972 to 1984 and triangulation surveys in the Strait of Juan de Fuca from 1892 to 1954 indicate that both regions are shortening at rates of 0.05 ± 0.02 and 0.22 ± 0.07 microstrain/year, respectively. Repeat leveling surveys along much of the Pacific Northwest coastline show steady uplift of the coastal region at a rate of up to 0.1 inch/year and subsidence of the inner coastal areas at a rate of 0.04 inch/year. The combined geodolite, triangulation, and uplift data may be explained by the seaward thrusting and uplift of the continental margin, with elastic horizontal extension and subsidence behind.

The Cascadia subduction zone shares many features with other subduction zones that are strongly coupled and have experienced very large earthquakes. The Cascadia zone is particularly like the locked zones of southwestern Japan, Colombia, and southern

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Chile. These zones have ruptured in sequences of several great, magnitude > 8 earthquakes, or have failed in single giant events of magnitude (M_w) 9. If the Cascadia subduction zone is locked, four or five earthquakes of magnitude (M_w) 8.1 could probably cover the length of the 700-mile-long Cascadia subduction zone. Larger earthquakes, at least in the magnitude (M_w) 8.5 range, could also be considered as a possibility. The overall dimensions of the Cascadia subduction zone are also similar to the zone that ruptured during the 1960 Chilean earthquake (M_w 9.5), the largest earthquake recorded in this century.

The plate convergence rates in the Cascadia subduction zone are similar to those in southwestern Japan, where the average repeat time of great earthquakes is between 100 and 250 years. The recurrence interval of giant, magnitude 9 earthquakes is less frequent. Fault displacements in magnitude 9 earthquakes may exceed 80 feet; their repeat time would probably be at least 400 years. At the current strain rate in the Pacific Northwest, it would take several hundred to a thousand years for horizontal strains to accumulate along the Cascadia subduction zone comparable to the strains in the 1960 Chile earthquake and the 1964 Alaskan earthquake (M_w 9.2). Coseismic extension in the central valley of southern Chile ranged from 25 to 50 microstrain; in the Alaskan earthquake they ranged from about 15 microstrain in the inland coastal areas to over 50 microstrain in the outer coastal areas. There is no conclusive evidence that large or great earthquakes have occurred in prehistoric time in the Pacific Northwest. However, at least one scientist has interpreted the succession of approximately 16 major turbidites (marine avalanche and landslide deposits) deposited in the last 6,600 years off the continental shelf of the Pacific Northwest as evidence of repeated large earthquakes in the Cascadia subduction zone about every 410 years.

The subduction of the Juan de Fuca and Gorda plates presents earth scientists with a dilemma. Is the subduction on the Cascadia zone a relatively benign tectonic process, with little or no earthquake activity? Or, does the Cascadia subduction zone fail during great earthquakes with a repeat time of 400 to 500 years? While the 150-year paucity of historic earthquakes supports the first explanation, it may be very difficult to prove that prehistoric earthquakes have not occurred.

Determining the Age of Faults

When a fault breaks the surface of the Earth, one side may be raised relative to the other producing a step-like scarp. Over the years, erosion alters the shape of the scarp, making it progessively smoother. Using a simple mathematical theory to model the erosion process, USGS scientists have developed a technique for determining the age of a surface rupture from the shape of the eroded scarp.

The scientists observed that the form of eroded fault scarps resembles the error function in mathematics. The error function is the fundamental solution to the diffusion equation for steplike initial conditions (for example, a newly formed fault scarp). The scientists theorized that the diffusion equation is a simple mathematical approximation to the erosional evolution of fault scarps. The age-dating technique is based on the assumption that mass transport due to erosion proceeds downhill at a rate proportional to the local topographic gradient: a steep fault scarp erodes more quickly than a shallow scarp. The equation permits the estimation of the age of fault scarps where it is impossible to determine their age by radiometric techniques.

Meers Fault, Oklahoma

The likelihood of large earthquakes in the Central United States was considered for many years to be small. The region was generally regarded to be geologically quiescent. With the exception of the New Madrid rift area of the central Mississippi Valley, only small-magnitude earthquakes have occurred historically in the midcontinent of the United States. In 1983, evidence for geologically recent activity was found on the Meers fault near Lawton in southwest Oklahoma. Initial studies of the fault's youthful scarp, which extends nearly 16 miles and locally is as much as 15 feet high, suggest that the scarp probably formed during at least one large, prehistoric earthquake.

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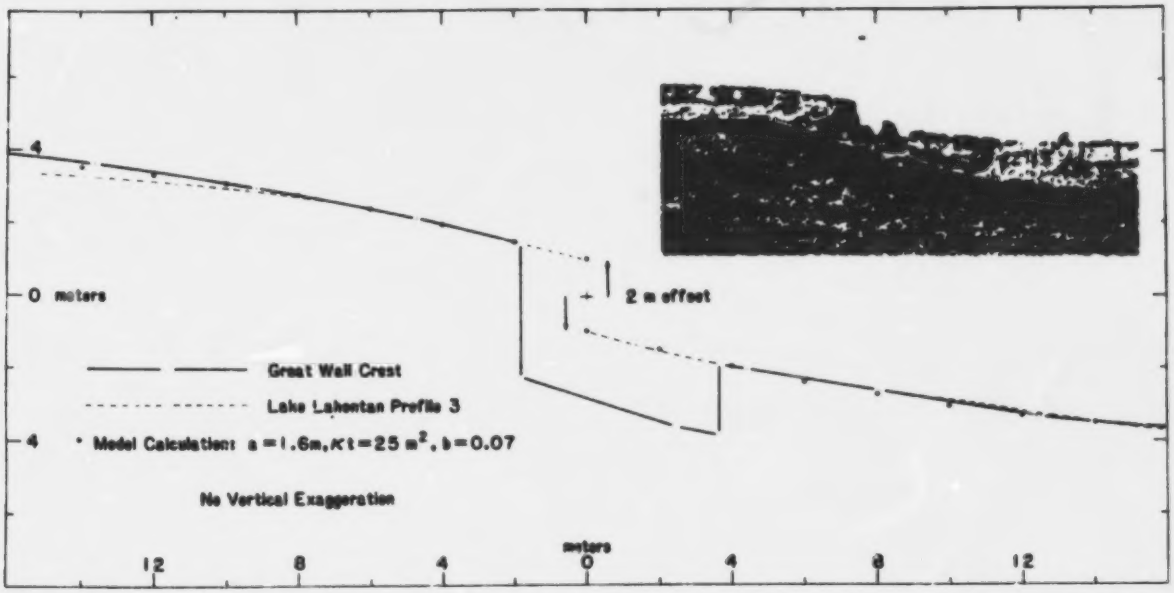

The Great Wall of China southwest of Shizuishan, Ningxia-Hui Autonomous Region, was built across an eroded fault scarp approximately 12,000 years old. During an earthquake in 1739 A.D. the wall itself was broken by renewed movement on the fault. The age of the earlier displacement was determined by analysis of the topography using a diffusion equation (curve). The earlier displacement was about 60 percent larger than the historic offset.

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Geologists from the USGS and the Oklahoma Geological Survey (with support from the Nuclear Regulatory Commission) excavated two trenches across the Meers fault in March 1985 to document the near-surface deformation associated with movement on the fault, and to determine the recency and recurrence of earthquakes on the fault. The trenches revealed that a single episode of reverse fault movement with about 10 feet of vertical offset had occurred in the last 2,000 years. The surface deposits were warped and deformed by the fault movement in a southwest-dipping flexure. Some of the movement caused the north block to rise up and override the south block along the north-dipping fault plane. Three samples of soil-derived humus that closely constrain the time of surface faulting were collected from the trenches. The samples revealed that the last offset on the Meers fault occurred sometime around 1,360 ± 50 to 1,730 ± 55 years B.P. (Before Present). One of the trench exposures suggested that there was a lengthly interval, perhaps tens of thousands of years, between the most recent offset and the last previous offset. In the exposure, gravels believed to be of middle-to-late-Pleistocene age were offset about the same amount as the surface deposits. The very similar offset implies that there was only one major faulting episode since deposition of the gravel.

A crude, long-term slip rate of about 0.8 inches/1,000 years was estimated assuming a net slip of 9.9 feet, and an age of 125,000 years for the offset, Pleistocene-age gravels. If the age of the alluvium is older, the slip rate will be less; if the net slip is larger because of lateral slip, the slip rate will be greater. In spite of these large uncertainties, the slip rate is consistent with the slip rates expected in intraplate environments.

Regional Earthquake Hazards Assessments

The Regional Earthquake Hazards Assessments Element was established to provide integrated comprehensive research on the source, size, frequency of occurrence, and the physical effects of earthquakes in major earthquake-prone urban areas of the United States. Integrated syntheses and assessments of earthquake hazards are needed for implementation of specific loss-reduction measures at the local level. Rather than having a small level of activity in several areas simultaneously, this element requires concentrated and coordinated attention to one or two urban areas and calls for a synthesis of multidisciplinary efforts and talents. Users of this information (for example: Federal, State, and local government agencies involved in emergency response, building safety, and planning) cannot find such an integrated synthesis and assessment of earthquake hazards in the scientific literature. Also, loss estimates have not been updated in most urban areas for many years and the risk may be seriously underestimated due to the sharp increase in building wealth.

A surprisingly large number of urban areas in the United States are at risk from earthquakes. These include the principal cities of the westernmost United States (San Francisco, Los Angeles, San Diego, Seattle, Salt Lake City), Alaska (Anchorage), and Hawaii (Hilo), as well as major urban areas of the central Mississippi Valley (St. Louis, Memphis) and the Northeast (New York, Buffalo).

The first integrated seismic hazards assessment of a major earthquake-prone urban region was prepared in the 1970s for the San Francisco Bay area of California as part of a joint USGS-Department of Housing and Urban Development multidisciplinary planning study of the metropolitan area. A second USGS urban earthquake hazards assessment, of the Los Angeles region, was completed in 1985.

To address the earthquake hazards of all areas of the United States, the USGS has initiated earthquake hazards and risk assessments in several other major urban areas by fostering partnerships with universities, the private sector, local government, and other State and Federal agencies, and by utilizing past research. Priority study areas include: (1) the Wasatch Front of Utah; (2) Puget Sound, Washington; (3) Anchorage, Alaska; (4) southern California; (5) northern California; (6) the central Mississippi Valley; (7) Charleston, South Carolina; (8) the Northeastern United States; and (9) Puerto Rico.

Each regional earthquake hazards assessment includes at least one of five interrelated components:

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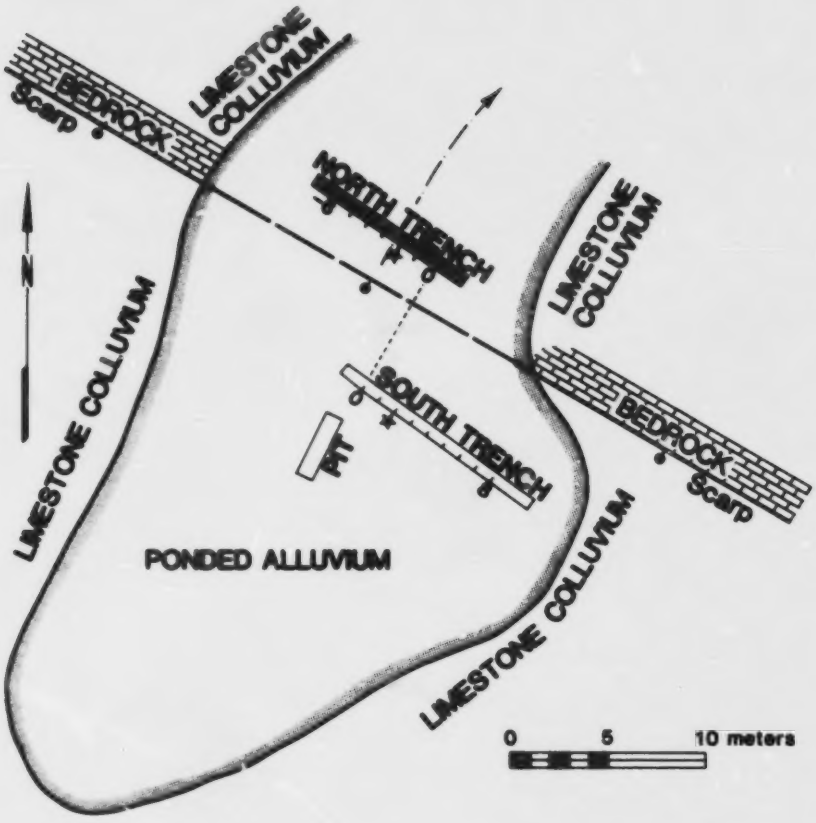

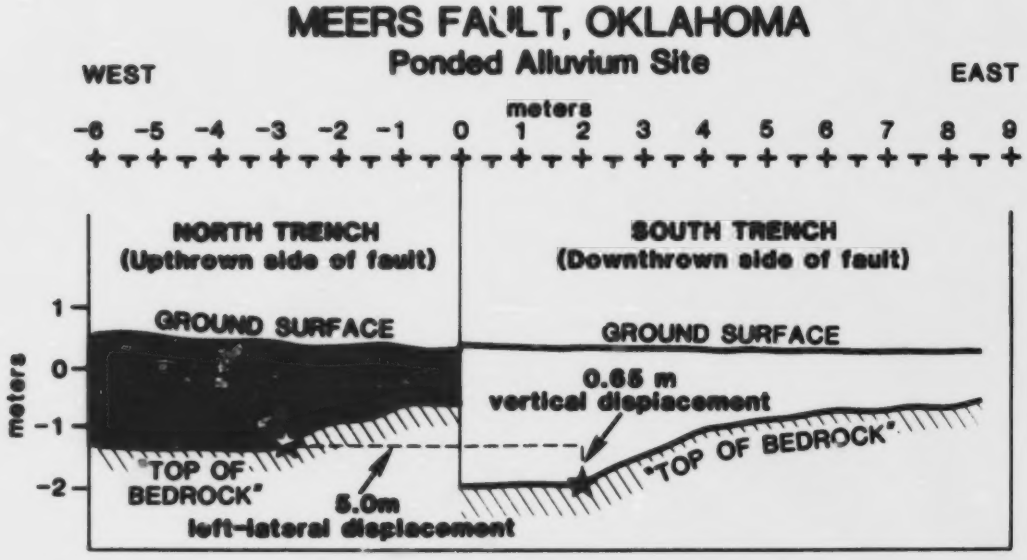

Two trenches (top) excavated across the Meers fault near Lawton in southwest Oklahoma revealed evidence for left-lateral movement on the fault during the last 2,000 years. An inflection point on the bedrock surface in the two trenches (bottom) was offset to the left across the fault approximately 5 meters (17 feet).

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- Information Systems. Produce quality data along with a comprehensive information system, available to both internal and external users, for use in earthquake hazards evaluations, risk assessment, and implementation of loss-reduction measures.
- Synthesis of Geological and Geophysical Data for Evaluation of Earthquake Hazards. Synthesize reports describing the state-of-knowledge about earthquake hazards (ground shaking, surface faulting, earthquake-induced ground failure, and tectonic deformation) and recommend future research to increase the state-of-knowledge required for the creation and implementation of loss-reduction measures.
- Ground Motion Modeling. Produce deterministic and probabilistic ground-motion models and maps of the ground-shaking hazard with commentaries on their use.
- Loss Estimation Models. Devise economical methods for acquiring inventories of structures and lifeline systems in urban areas, to create a standard model and commentary for loss estimation, and to produce loss and casualty estimates for urban areas.
- Implementation. Foster the creation and implementation of hazard-reduction measures in urban areas, providing high-quality scientific information that can be used by local government decisionmakers as a basis for implementing hazard mitigation and loss reduction measures.

Earthquake Hazards of the Wasatch Front, Utah

A major, 3-year assessment of the earthquake hazards of Utah's Wasatch Front was concluded in Fiscal Year 1986. The assessment was focused on the 10-county, Brigham City-Salt Lake City-Ogden urban corridor, which lies astride the active Wasatch fault. More than 85 percent of Utah's population lives near the fault. Although the fault has not ruptured in any earthquake since Mormon pioneers arrived in 1847, geologic studies have indicated that moderate-to-large earthquakes have occurred on the fault about every 50 to 400 years. The Wasatch Front regional earthquake hazards assessment was conducted by the USGS in cooperation with the Utah Geological and Mineral Survey. The study had three principal goals: (1) estimation of recurrence rates and maximum size of earthquakes; (2) calculation of the nature and severity of the expected ground shaking; and (3) identification and mapping of areas where earthquake shaking may induce landslides, liquefaction, surface faulting, and other ground failures.

Wasatch Fault Earthquake Potential Reassessed

Previous USGS-sponsored investigations of earthquake recurrence on the Wasatch fault had suggested that the fault is composed of six major segments, each the source of repeated past large earthquakes probably of magnitude 6-3/4 to 7-1/2. New detailed mapping, analysis of scarp profiles, and new stratigraphic and chronologic control, however, has revealed that the Wasatch fault may be composed of as many as 10 segments. The new findings change current assessments of the earthquake potential of the Wasatch fault.

The new subdivisions are based on recency of fault movement, geometric patterns of surface ruptures and amounts of offset, and history of movement during the Holocene and late Pleistocene. The 10 segments have surface traces that are 9 to 36 miles in length (their average trace length is about 21 miles). The lengths of the new proposed segments are generally comparable with the lengths of surface ruptures in historic large-magnitude earthquakes in the Basin and Range Province and in the western Rocky Mountains, such as the 1959 magnitude 7.5 Hebgen Lake, Montana, earthquake (16 miles), and the 1983 magnitude 7.3 Borah Peak, Idaho, earthquake (22 miles).

The increase in the number of identified fault segments from 6 to 10 decreases the size of the largest earthquake that might be expected to occur on the Wasatch fault. The new subdivisions strongly argue that the maximum earthquake on the Wasatch fault is no greater than about magnitude 7-1/2. However, the larger number of fault segments increases the expected frequency of earthquake events.

Wasatch Fault Earthquakes and Ancient Lake Bonneville

During the Ice Ages of the Pleistocene, much of western Utah was repeatedly covered by

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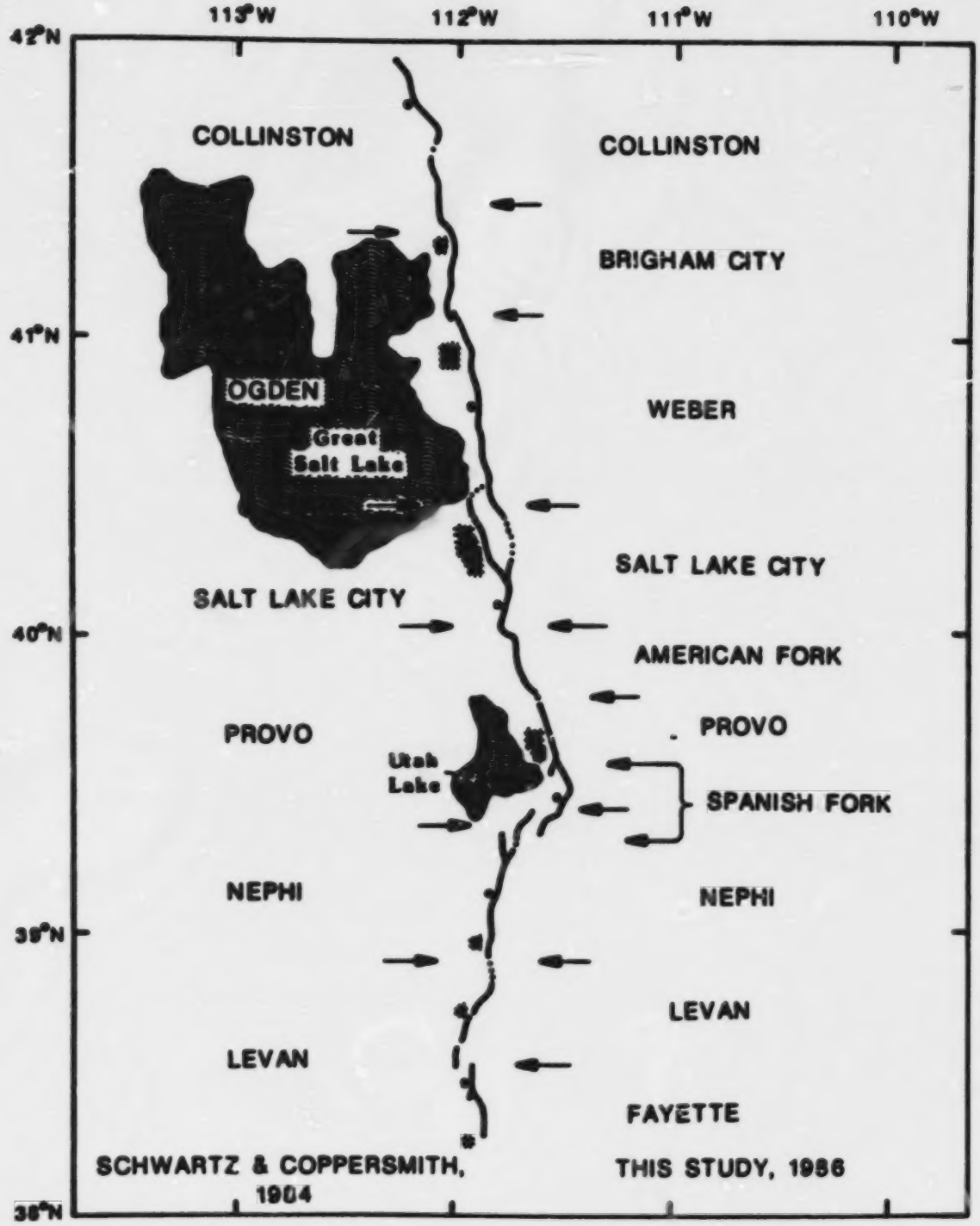

New mapping of Utah's Wasatch fault has revealed that the fault may be composed of as many as 10 separate segments (right). Previous studies had indicated that the fault was composed of only six major segments (left). The new findings decrease the size of the maximum expected earthquakes, but increase the frequency of such events.

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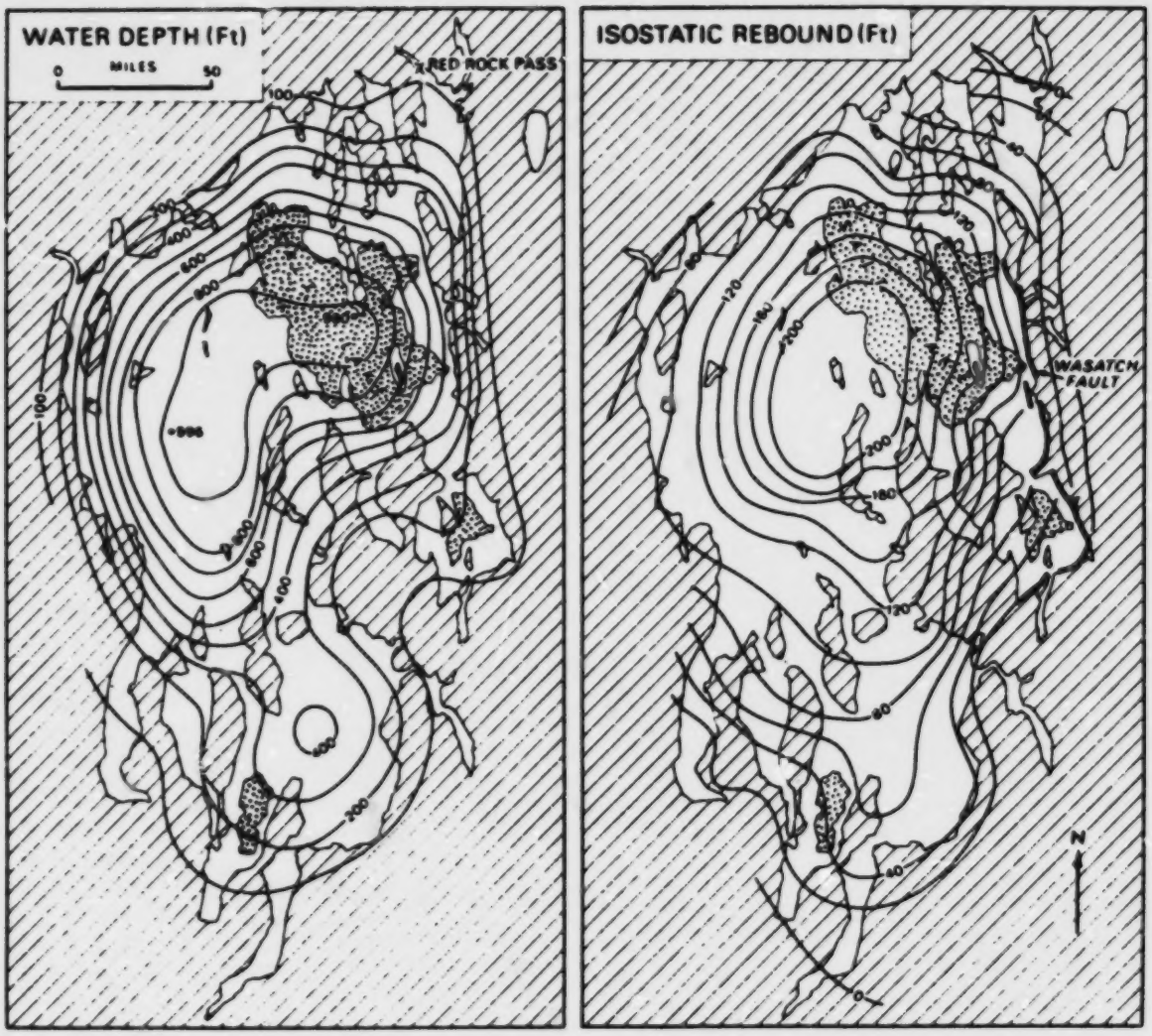

Pleistocene Lake Bonneville, Utah. A. Maximum water depth (in feet) averaged over circles of 25-mile radius. The maximum former extent of Lake Bonneville is outlined in white; stippled areas indicate modern lakes. Drainage of the Pleistocene lake occurred when an outlet was cut at Red Rock Pass. B. Isostatic rebound (in feet) resulting from the removal of lake water, as measured by the deformation of the Bonneville shoreline.

giant pluvial lakes that formed during major glacial episodes. At their maximum, these lakes filled the Bonneville basin westward from the Wasatch Front to the Nevada border. Lake Bonneville, the last and largest of these former lakes, had an area of nearly 20,000 square miles (nearly equal to that of Lake Michigan) and an extreme depth of more than 1,000 feet.

Recent USGS studies of the slip rates on the Wasatch fault have revealed that the rate of earthquake activity on the fault apparently accelerated with the formation of Lake Bonneville, and may have declined since the disappearance of the lake. The average slip rate on the fault was low (0.004–0.008 inches/year) before the most recent, and deepest lake cycle in the Bonneville basin approximately 35,000 to 12,000 years ago. The slip rates recorded in sediments of less than 15,000 years ago, however, are more than 10 times greater than those before the formation of Lake Bonneville (typically 0.03–0.06 inches/year).

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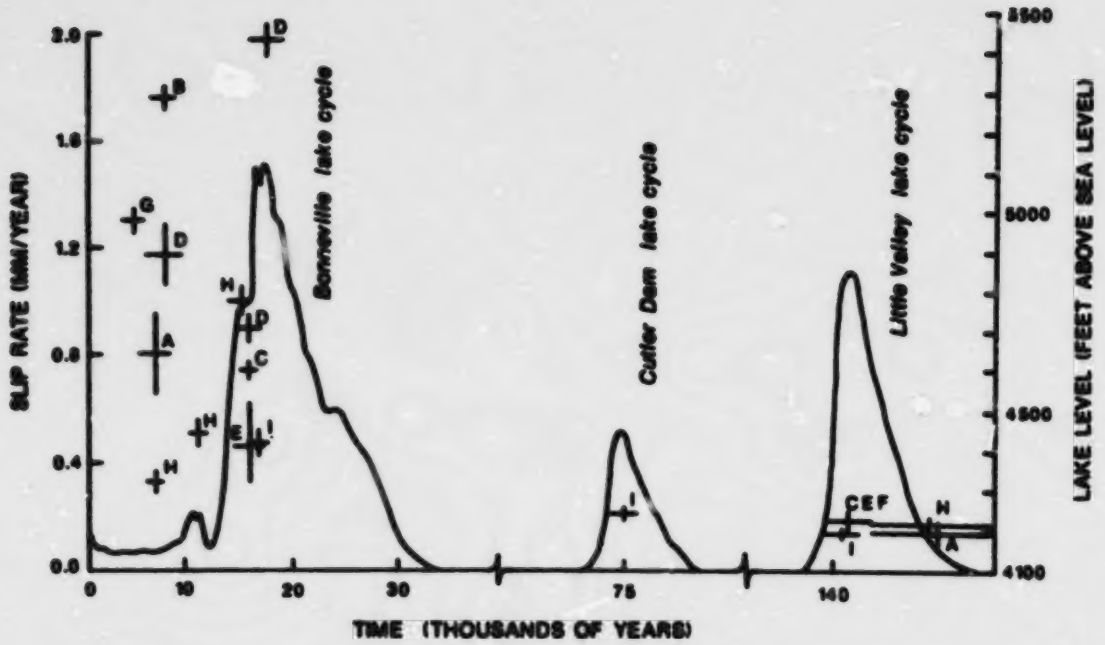

LOCATIONS OF SLIP-RATE DETERMINATIONS

A	Gardner Creek, Nephi segment, Wasatch fault zone
B	North Creek, Nephi segment, Wasatch fault zone
C	Santaquin Valley, Nephi segment, Wasatch fault zone
D	Hobble Creek, Spanish Fork segment, Wasatch fault zone
E	Dry Creek, American Fork segment, Wasatch fault zone
F	Little Cottonwood Creek, Salt Lake City segment, Wasatch fault zone
G	Kaysville, Weber segment, Wasatch fault zone
H	Jim May Canyon, Brigham City segment, Wasatch fault zone
I	West Valley fault zone (Keaton and others)

Schematic diagram showing slip rates determined along the Wasatch fault from deposits of post and pre-Bonneville lake cycle age (left axis) and a hydrograph of the Bonneville basin for the past 150,000 years (right axis).

Lake Bonneville may have played an important part in increasing activity along the Wasatch fault. During the highest stand of the lake, the waters of Lake Bonneville imposed a weight load on the Bonneville Basin equivalent to nearly 400 to 500 feet of sedimentary rock. Essentially all of the load was exerted on the downthrown (west) block of the Wasatch fault. Lake Bonneville's greatest depths were just a few miles from the central and northern parts of the fault, where high slip rates have been measured. The increased hydrostatic head would have increased pore pressure at depth along the fault everywhere but the two southernmost segments of the fault, which were well east of Lake Bonneville. About 15,000 years ago, the catastrophic fall of the lake from the Lake Bonneville level to the Provo level (about 330 feet lower) was accompanied by rapid isostatic uplift of the basin, and the accumulation of thick wedges of sediment deposited by major streams flowing from the Wasatch Range. Subsequent dessication of the lake to near present levels by 10,000 years ago was accompanied by even more isostatic rebound; the net rebound in deep parts of Lake Bonneville was almost 200 feet. This crustal rebound (an uparching) may have contributed to east-west extensional forces that are present in the Basin and Range.

Ground Shaking in Salt Lake Valley

USGS studies to measure the effects of soils (unconsolidated sediments) on the level of

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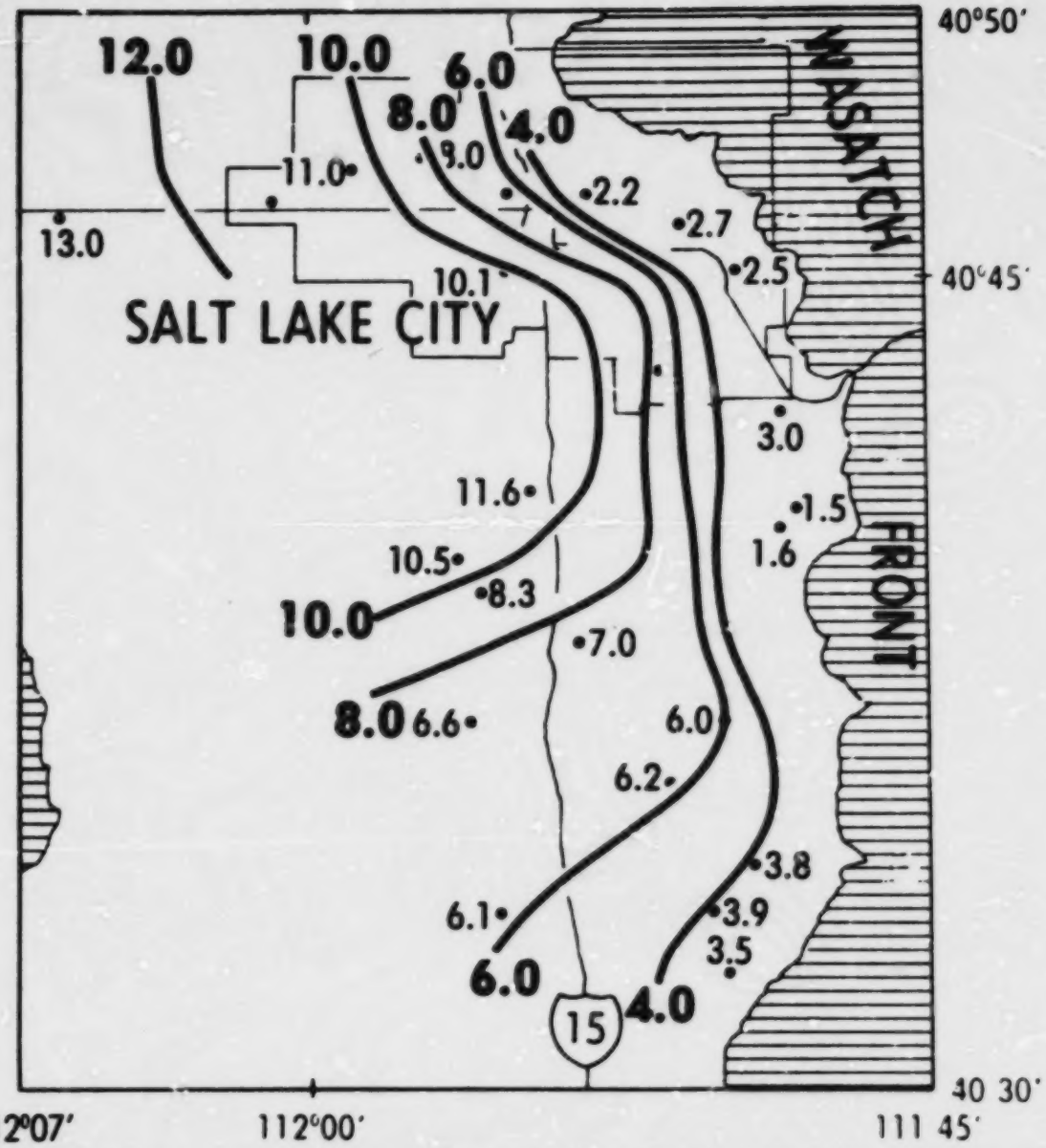

Estimated horizontal ground response in the Salt Lake City area, Utah, for the period band of 0.2 to 0.7 seconds. The contours compare ground shaking levels on soils as compared to rock. The map indicates that ground shaking levels in western Salt Lake City will be 10 to 12 times greater than on sites underlain by bedrock in the Wasatch Front.

ground shaking have revealed that urban areas along the Wasatch Front built in the middle of alluvium-filled valleys will experience for moderate-size earthquakes, ground-shaking levels that are 3 to 4 Modified Mercalli intensity units larger than sites on the edges of the valleys. For maximum-magnitude earthquakes, these effects indicate that the entire valleys will experience maximum levels of ground shaking. Although these effects are not as serious as those that produced damage in Mexico City, they must be considered in the design of high-rise structures.

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Potential Earthquake Losses in the Salt Lake City Area

The potential losses from future earthquakes in the Salt Lake City area have been calculated from estimates of the probabilistic ground motions of future earthquakes in the Wasatch Front, and inventories of building wealth and vulnerability in the Salt Lake City area. The ground motions were calculated from a model incorporating fault locations, earthquake frequency, and soil effects. The loss assessment suggests that in a 50-year period, Salt Lake City will experience $1 billion in earthquake losses (1985 dollars). If a magnitude 7.5 earthquake were to occur on the Wasatch fault, losses as great as $1.7 billion are expected. The loss estimates do not include additional losses that may be caused by ground failure (landslides, liquefaction, etc.). Other losses from dam failures and life-line interruptions (*e.g.*, breaks in gas pipelines, downed power lines) are also expected.

Earthquake Hazards of the Helena Area, Montana

Several hundred earthquakes have been felt in the Helena, Montana, region since it was first settled in 1864. Most of these shocks have been of weak to moderate Mercalli intensity (II–IV). In 1935, a destructive earthquake and a powerful aftershock, both of intensity VIII, caused four deaths and property damage exceeding $19,000,000 (1979 dollars). The earthquake (magnitude 6-1/4) of October 18, 1935, caused extensive damage in Helena and East Helena and resulted in two fatalities and several tens of injuries. Altogether, about 300 buildings in Helena, including many large structures, sustained some form of serious damage from the shock. The powerful aftershock (magnitude 6) on October 31 caused additional severe damage in Helena and East Helena and resulted in two fatalities. Many structures weakened by the previous shocks were further damaged by the aftershock or collapsed.

View of the north wing of the Helena (Montana) High School following the major aftershock on October 31, 1935. This facility, newly completed in August 1935 at a cost of about $500,000, was severely weakened by the main shock on October 18.

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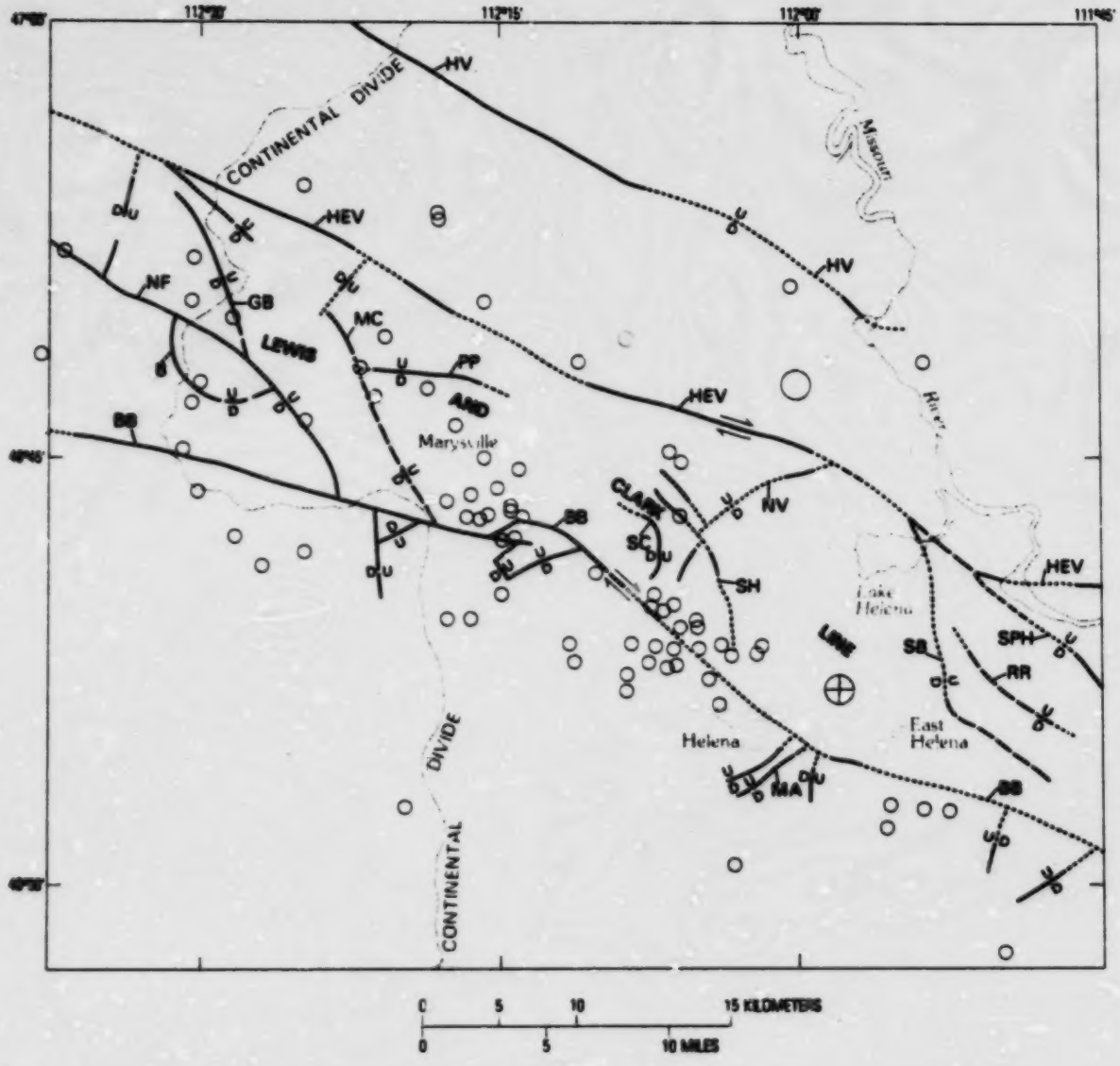

EXPLANATION

- EPICENTERS LOCATED IN 1973—From Friedline and others (1976, fig 6)
- EPICENTER OF MAIN SHOCK OF 1935 EARTHQUAKE—Recomputed by Dewey and others (1972, p. 888)
- EPICENTER OF PRINCIPAL AFTERSHOCK OF 1935 EARTHQUAKE—From Neumann (1937, p 46)
- STRIKE-SLIP FAULT—Arrows show inferred relative direction of horizontal movement; dashed where inferred; dotted where concealed
- NORMAL FAULT—Dashed where inferred; dotted where concealed; U, upthrown side; D, downthrown side

Map showing the location of some earthquake epicenters and the traces of principal faults in the Helena, Montana, area. Named faults: B, Beartrap; BB, Bald Butte; GB, Granite Butte; HEV, Helena Valley; HV, Hilger Valley; MA, Mount Ascension; MC, Marsh Creek; NF, North Fork; NV, Northwest Valley; PP, Prickly Pear; RR, Regulating Reservoir; SB, Spokane Branch; SC, Silver Creek; SH, Scratchgravel Hills; SPH, Spokane Hills.

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A new comprehensive study of the earthquake hazards of the Helena area, Montana, has just been published as USGS Professional Paper 1316. The report, *Geology, Earthquake Hazards, and Land Use in the Helena Area, Montana — A Review*, describes the local geology, potential earthquake hazards, and local geologic conditions that may contribute to seismic hazards and briefly outlines the implications these factors have for land use and for earthquake protection. The study identifies six faults as potentially active and likely to sustain future movement. They are the Bald Butte fault and the Helena Valley fault, both strike-slip faults many tens of miles in length; and the Scratchgravel Hills, Spokane Bench, Regulating Reservoir, and Spokane Hills faults, all normal faults less than 13 miles in length. One of the faults, the Bald Butte, passes directly beneath downtown Helena. The ancient glacial sediments and alluvium underlying Helena Valley are capable of amplifying earthquake ground motion in future strong earthquakes, and are locally susceptible to ground failure and liquefaction. Enhanced shaking on these materials was probably a major cause of widespread damage in Helena during the earthquake of 1935.

EARTHQUAKE PREDICTION RESEARCH

The goal of earthquake prediction is to give a warning of large, potentially damaging earthquakes at a time interval long enough to allow appropriate actions by the public and private sectors and with enough precision to avoid sustained disruptive effects that the prediction response may have on society. Population growth and industrial development, concentrated in areas of earthquake hazard, have created a situation in which casualities and property losses for some expected future earthquakes will greatly exceed those of any historic earthquake disaster in the United States. A large earthquake in a heavily populated area can be expected to result in regional disruption of public services, transportation systems, and communications. A great (magnitude 8) southern California earthquake might impact the Nation at a scale surpassing any disaster the United States has suffered in its own territory since the Civil War. Damage to transportation links and to key industrial facilities concentrated in the vicinity of the earthquake epicenter could affect the Nation as a whole due to reduced economic activity and defense preparedness.

Earthquake prediction is a primary means for enhancing the effectiveness of disaster planning preparedness activities, and one means for mitigating the effects of an earthquake. Reliable earthquake prediction has the potential for greatly reducing casualities, loss to contents of buildings, and structural losses due to indirect causes such as fires. Additionally, critical activities, such as the transfer of toxic substances, airport operations, high precision machining, and surgery could benefit from reliable predictions.

The USGS conducts earthquake prediction research to establish procedures and knowledge needed for the reliable prediction of the time, place, and magnitude of damaging earthquakes. The USGS supports the primary research and data-gathering efforts in earthquake prediction in the United States through a program that involves Government scientists, interacts with foreign earthquake prediction programs, and provides support for earthquake prediction studies in the academic community and private sector. Under the *Organic Act of 1879* (43 U.S.C. 31(a)) and the *Disaster Relief Act of 1974* (42 U.S.C. 5201 *et seq*.; P.L. 93-288), the USGS has general and broad responsibility to investigate earthquakes and earthquake hazards, to notify appropriate Federal, State, and local authorities of these hazards, and to provide information as necessary to insure that timely and effective warning of potential disasters is provided. The Director of the Geological Survey through the Secretary of the Interior has been delegated the responsibilities of the *Disaster Relief Act of 1974* to issue disaster warnings "...for an earthquake, volcanic eruption, landslide, or other geologic catastrophe." In the 1980 reauthorization of the *Earthquake Hazards Reduction Act of 1977* (Section 101(e), P.L. 96-472), the Director of the USGS was also given the authority to issue an earthquake advisory or prediction as deemed necessary.

Earthquake prediction research includes field, laboratory, and theoretical investigations of

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earthquake mechanisms and of the physical characteristics of fault zones directed toward

- Collection of baseline geophysical data in areas of seismic risk and development of a fundamental understanding of the physical laws governing the earthquake cycle.
- Development of earthquake prediction methods and techniques to provide a rational basis for estimates of increased earthquake potential and short-term predictions.
- Evaluation in probabilistic terms of the relevance of various geophysical, geochemical, and hydrological data to increased earthquake potential.
- Development of theoretical and laboratory models of the earthquake process to guide observational experiments and to test empirical, predictive techniques.
- Determination of the physical mechanism for reservoir-induced seismicity and development of techniques for predicting and mitigating this potential hazard.

Theoretical, Laboratory, and Field Studies

Theoretical and laboratory models have been constructed by USGS scientists to study dynamic fault behavior using realistic geometries and fault properties under realistic physical conditions. Field studies of fault properties and physical conditions at depths where earthquakes occur are used to make the laboratory and theoretical models and experiments more accurate and representative of actual Earth conditions.

Earthquake Prediction Monitoring Network

A major part of the USGS Earthquake Prediction Research activity envolves developing, deploying, and maintaining instrumentation to obtain geophysical, geochemical, and hydrological measurements in fault zones before large earthquakes. Rather than comprehensive studies of a specific region or fault segment, these efforts are aimed at testing the reliability of instruments under various conditions and determining the sensitivity of certain phenomena to expected premonitory variations. Data are collected in the Western United States, Alaska, and at certain foreign sites where conditions are favorable for extending the earthquake prediction data base rapidly. In most cases, sites within a given region will measure only one type of data. The objective is to establish statistical relationships, if possible, between proposed premonitory phenomena and large earthquakes including false-alarm and no-alarm occurrences.

The main component of the field measurement program is the telemetered network of seismometers that monitor the entire length of the 690-mile-long San Andreas fault system in California for the purpose of detecting and accurately locating all earthquakes of magnitude 1.5 and larger. Data from the network are used to map active faults in the subsurface, determine the nature of fault motion, and monitor variations in activity for indications of changing physical conditions in the fault system. The northern half of the California network (consisting of about 300 seismometers) is maintained by the USGS from its Western Region Headquarters in Menlo Park, California, where data are recorded and analyzed. The southern half of the network (about 250 stations) is maintained jointly by the California Institute of Technology and the USGS. The data are recorded and analyzed in Pasadena.

In addition to Statewide coverage by the seismic network, the accumulation and release of strain is monitored on an annual basis through resurveys of an extensive system of 25 geodetic strain networks in California and Nevada. Several hundred trilateration lines varying in length from 6 to 22 miles are surveyed with laser-ranging geodolites. These measurements provide critical information on the rate of strain accumulation (crustal deformation) on specific faults and have provided evidence for regional-scale variation in the crustal loading rate. To supplement the relatively infrequent geodetic strain measurements being made along the San Andreas fault, a variety of continuously operating strain instruments are being used. The two primary instrument systems are borehole dilatometers and creepmeters. Other continuously operating strain-sensitive instruments that are being monitored include

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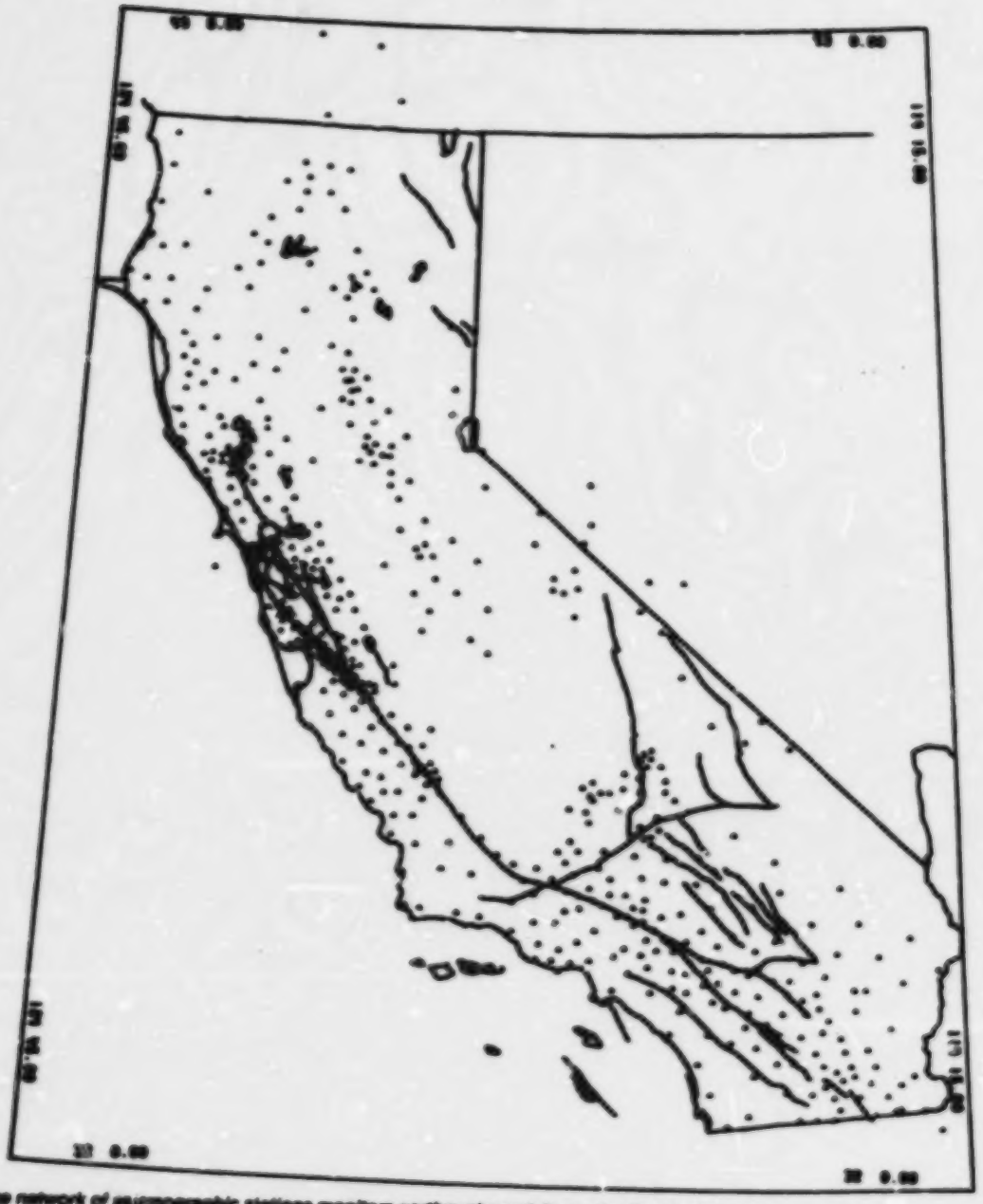

A dense network of seismographic stations monitors earthquake activity on the San Andreas fault system and in other seismogenic areas of California.

(1) shallow borehole tiltmeters, (2) surface strainmeters, and (3) magnetometers. Short- to medium-term strain variations are measured periodically with 2-color laser geodimeters at Parkfield and Palmdale, and at Long Valley calders near Mammoth Lakes.

Concentrated Studies

The third principal part of the prediction effort involves concentrated studies of faults or seismogenically active areas where there is an increased potential for moderate-to-lar(ge),

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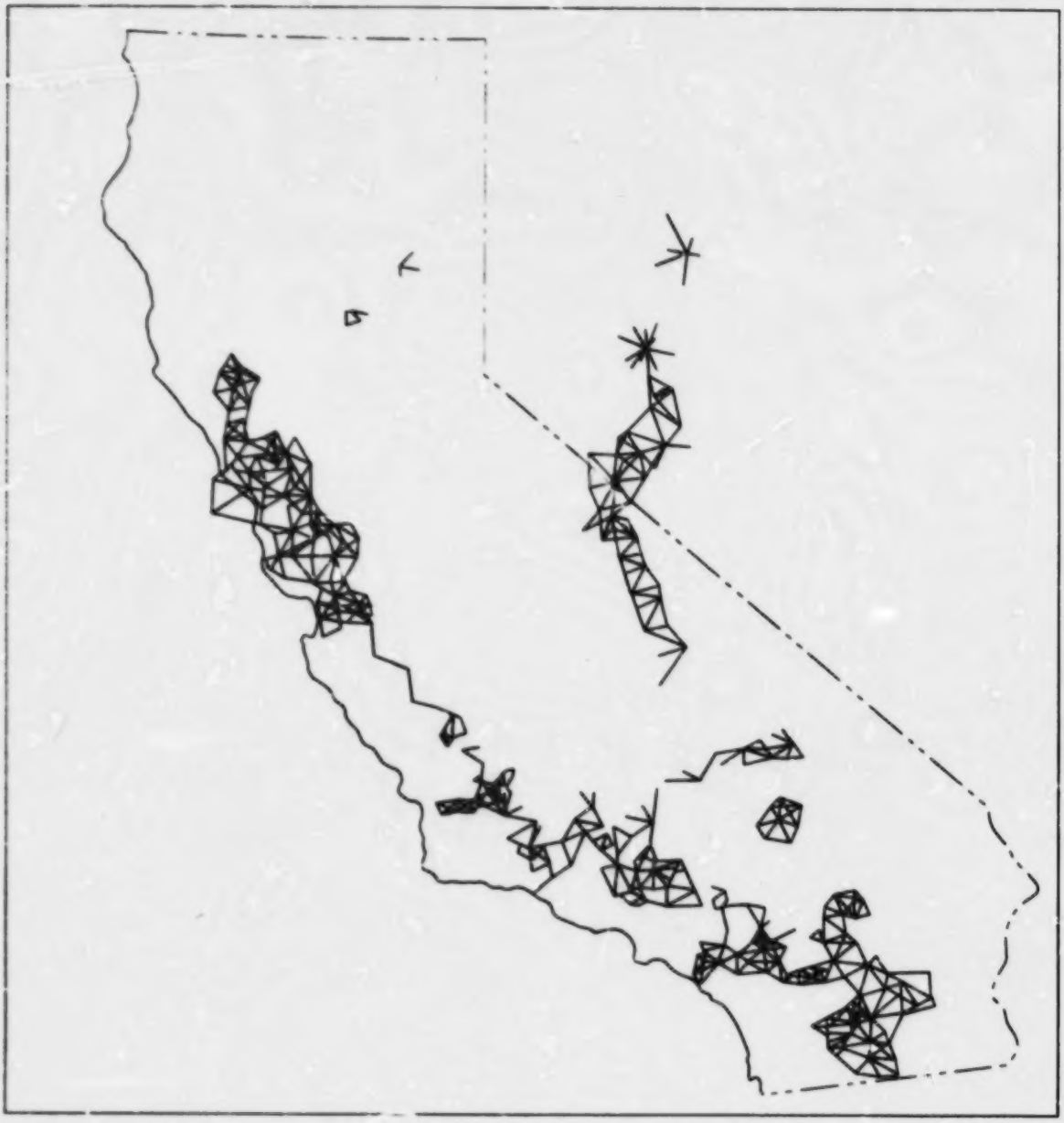

Geodetic triangulation networks in California and Nevada.

potentially damaging earthquakes. The USGS is studying intensively the central reach of the San Andreas fault near Parkfield, where there is a high potential for a magnitude 6 earthquake in 1988 ± 5 A.D. The USGS is also closely observing the Long Valley-Mammoth Lakes, California, area, where repeated earthquake activity and inflation of the caldera's resurgent dome has raised concern over the possibility of renewed volcanism along the south moat of the caldera. Data from cluster of instruments near Parkfield and Mammoth Lakes and individual

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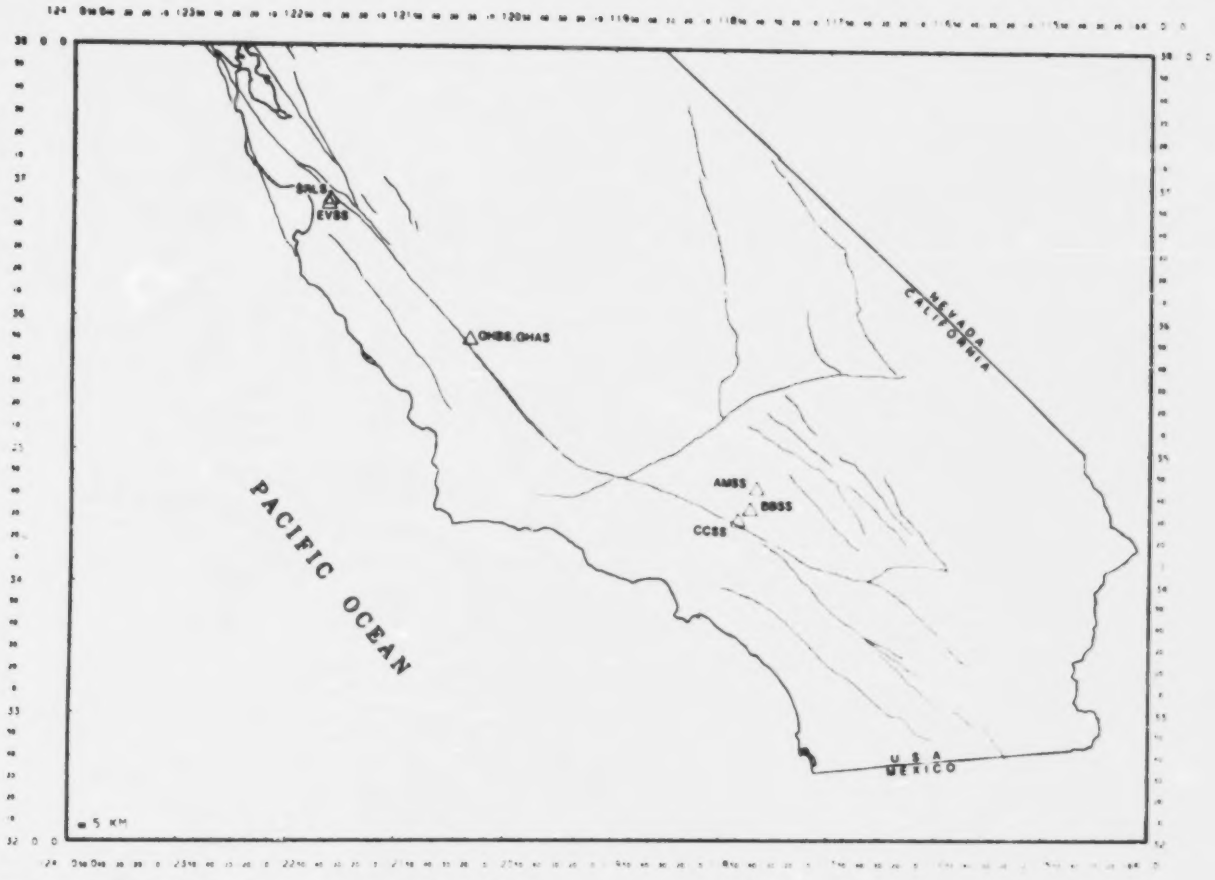

Borehole volumetric strainmeters operated by the USGS in central and southern California. The strainmeters use oil-filled cylinders to measure small changes in volume. Data from the instruments are telemetered at 10-minute intervals to the USGS prediction data and analysis center in Menlo Park, California.

instruments elsewhere are transmitted to a data center at Menlo Park where they are reviewed daily by scientists and monthly at formal data reviews.

In southern California, instruments and measurement networks have been developed and are maintained by investigators of several institutions. The instruments and survey sites are widely and sparsely distributed from Santa Barbara County south to the Mexican border. There is a dense concentration of crustal-deformation sensors for instrument development and calibration at Pinon Flat, located 60 miles northeast of San Diego and operated by the University of California there. These instruments are located in the vicinity of a zone of high seismic potential on the San Jacino fault near Anza.

Long-Term Earthquake Prediction

Research supported by the USGS on the problem of long-term earthquake prediction (earthquake potential) and estimates of strong ground shaking due to earthquakes has proceeded more rapidly than originally thought possible. Geologists at the USGS, the California Institute of Technology, and other institutions have, through detailed studies of fault zones, demonstrated that dates of large prehistoric earthquakes can be estimated from the geologic record. Scientists from Lamont-Doherty Geological Observatory, the University of California, the California Institute of Technology, and the USGS have combined these results with seismological and other data to provide quantitative estimates of recurrence times of earthquakes in California, Alaska,

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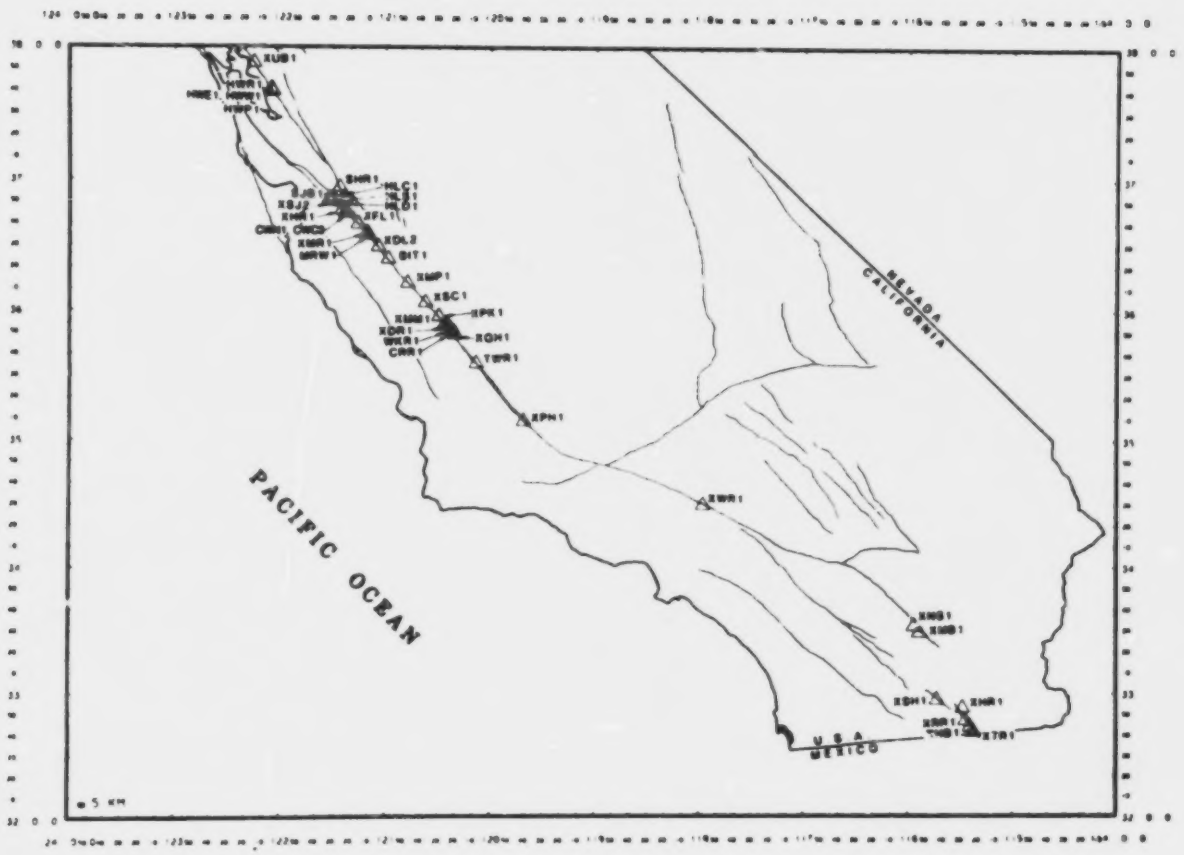

Slip on the San Andreas fault and several subsidiary faults in California monitored by a network of 37 creepmeters operated by the USGS and the California Institute of Technology. The creepmeters are 30- to 60-foot-long wires stretched through buried tubes that cross the faults at angles of 22 to 45 degrees. Data are recorded in the field, and in some cases, are telemetered.

Nevada, and elsewhere. From estimates of recurrence times, or the length of the seismic cycle, and knowledge of the last large earthquake in a region, general or long-term predictions (accurate within a few years or decades) may be made.

Forecast of the 1985 Mexico Earthquake

The most destructive earthquake in North America in this decade occurred on September 19, 1985, when central Mexico was severely shaken by a great, magnitude (M_s) 8.1 earthquake. The earthquake occurred in the Michoacan seismic gap, a segment of the Cocos-North American plate boundary where no major earthquakes had occurred for at least 70 years. The existence of a possible seismic gap in this portion of the plate boundary and general forecast of large earthquakes in the area had been made in 1981 in USGS-supported studies of earthquakes along the Middle America Trench. The studies were conducted by scientists at the California Institute of Technology. Although the specific time of the earthquake was not specified, the university scientists had determined that the average repeat times for earthquakes of magnitude ≥ 7.5 along the Trench was roughly 35 years. Two large earthquakes had ruptured the plate boundary north and south of the gap in the 1970's. The 1973 Colima earthquake (magnitude 7.6) had ruptured the zone northwest of the gap; in 1976, the Petatlan earthquake (magnitude 7.6) ruptured the zone to the southeast.

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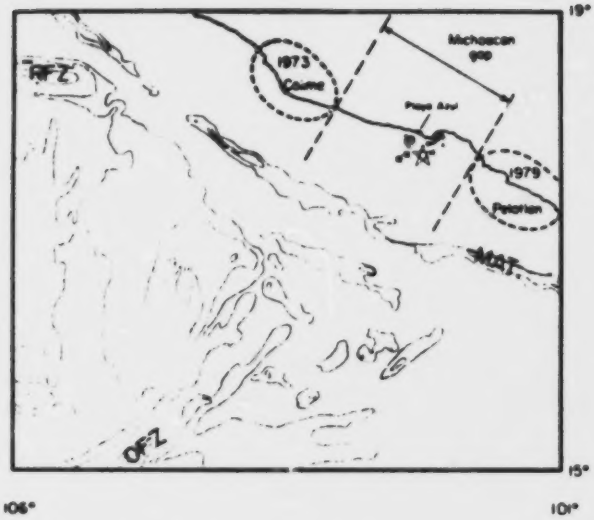

The Michoacan seismic gap. The aftershock areas of the 1973 Colima and 1979 Petatlan events are outlined. A magnitude 7.3 earthquake (star) occurred in the gap near Playa Azul on October 25, 1981. Asterisks indicate two foreshocks, 3 and 4 months before the 1981 earthquake. Crosses indicate aftershocks which occurred during 6 days after the main shock. Features of the seafloor shown are the Orozco Feature Zone (OFZ), the Middle America Trench (MAT), and the Rivera Fracture Zone (RFZ). (Figure, Journal of Geophysical Research, *American Geophysical Union.)*

The Mexico earthquake forecast was refined in a subsequent USGS-supported study published just four months before the September 19, 1985, earthquake. In that report, scientists from the California Institute of Technology and the University of California, Santa Cruz, observed that the Michoacan gap area could be capable of producing a large interplate event. The scientists noted that a large stress buildup, although difficult to evaluate, was suggested by the local seismic slip deficit. They concluded that the seismic potential of the area was unknown, but that the possibility of a large event could not be ruled out.

Short-Term Earthquake Prediction

Progress on the problem of short-term prediction, within a few hours or days of the event, has proven more difficult. For short-term prediction, it is necessary to identify and detect that portion of the seismic cycle just before a large earthquake occurs. This depends on there being accelerated deformation in the rock at the fault hours or days before failure. Simply stated, the central notion behind short-term earthquake prediction is that most mechanical systems when subjected to deformation, such as a stick being bent or the Earth's crust being strained, will not fail catastrophically without premonitory indications, such as rapid yielding or minor brittle fracturing just before failure. In the case of earthquake prediction, the central questions are whether or not these indications will occur at a magnitude and time in order to form the basis of a timely and reliable warning of an impending earthquake.

During the past several years, two important developments have strongly influenced the strategy by which research in short-term earthquake prediction is being pursued in California. First, continuing work between seismologists at the USGS in Menlo Park and at the University of California at Berkeley has strongly suggested that a magnitude 6 earthquake will occur along a 13-mile-long segment of the central San Andreas fault near Parkfield in 1988 ± 5. Second, because of the heightened risk of a great earthquake on the southern San Andreas fault north of Los Angeles (estimated as a 45 percent likelihood in the next 30 years) considerable thought has been given to the design of a second-generation earthquake prediction network in this region. This prototype operational earthquake prediction system ultimately would replace existing instrumentation, and the data obtained would be analyzed and monitored continuously.

Parkfield, California, Earthquake Prediction Experiment

In 1985, USGS and University of California, Berkeley, seismologists forecast that a moderate-size earthquake of magnitude 6 is likely to occur in the Parkfield, California, area within the next several years (1985-1993). The forecast was the first to be officially endorsed and accepted by both the National Earthquake Prediction Evaluation Council and the California Earthquake Prediction Evaluation Council. Parkfield lies along the San Adreas fault in a sparsely populated area of the California Coast Ranges about midway (170 to 180 miles) between San Francisco and Los Angeles. Five moderate (magnitude 6) earthquakes with similar features have occurred on the Parkfield

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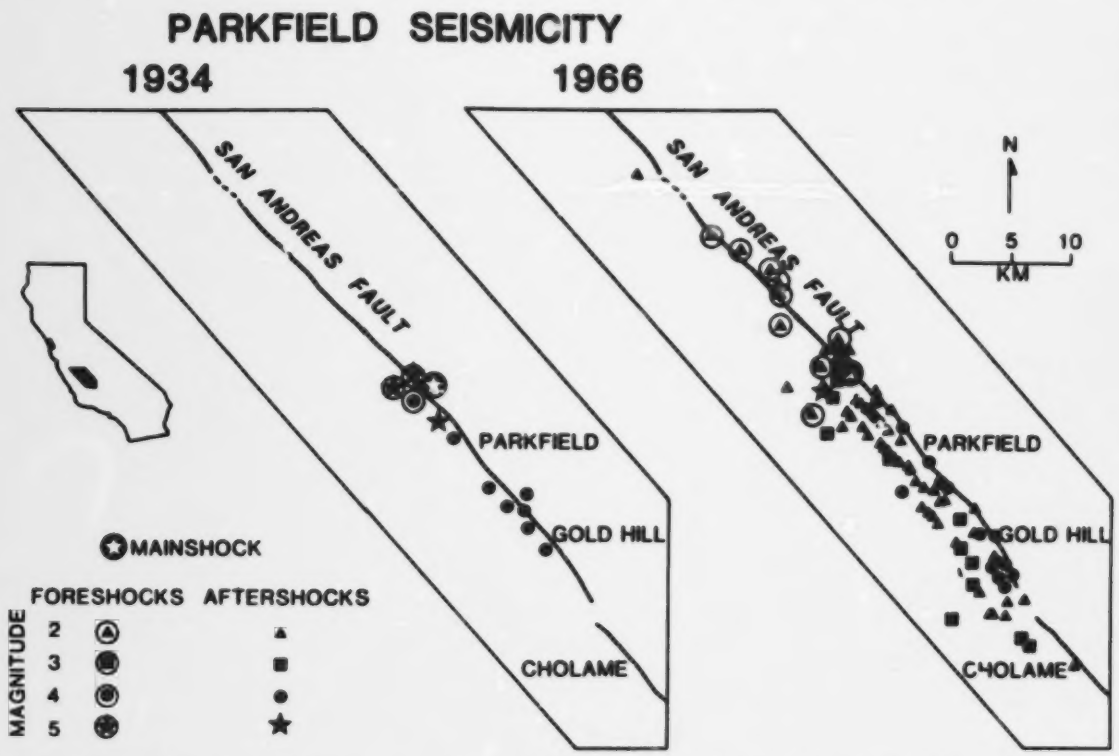
section of the San Andreas fault since 1857. The times between earthquakes (in 1881, 1901, 1922, 1934, and 1966) have been remarkably uniform, with a mean interval of 21.9 ± 3.1 years. (Although the time of the 1934 earthquake departs from the regular pattern by occurring a decade too early, the time of the 1966 earthquake conforms to the regular pattern, in that the 44 years between 1922 and 1966 is twice the mean interval.) If the next Parkfield earthquake conforms to the pattern, it will occur before 1993, most likely in early (January) 1988.

An earthquake prediction experiment has been established at Parkfield to observe the final stages of the process leading up to the earthquake. Four observational networks (seismic, geodetic survey, continuous strain, and creep) are now monitoring the central San Andreas fault near Parkfield. A very dense network of seismographic stations monitors details of seismicity within and near the preparation zone. Signals from the seismographs near Parkfield are telemetered continuously to the central data-processing facility in Menlo Park, California. The signals are automatically and continuously monitored by a real-time processor that, within a few minutes, routinely locates earthquakes in central California. Beeper and paging-systems have been established so that the responsible scientists are notified within minutes of all significant seismicity near the preparation zone. A dense geodetic network with line lengths of 3 to 19 miles spanning the fault has been measured every 1 to 2 years since 1969. Lengths of lines spanning the rupture zone are measured several times each week using a two-color laser distance-measuring geodimeter that is capable of resolving length changes of about 0.04 inches over 3- to 5-mile-long lines. Borehole volumetric strainmeters also are being installed in the Parkfield area to provide continuous data with a sensitivity of about 1 part per billion over periods of a few hours. In addition, a number of wire strainmeters (creepmeters) span the surface trace of the San Andreas fault near



Map of the Parkfield, California, area showing epicenters of earthquakes associated with the 1934 (left) and 1966 (right) Parkfield earthquakes. In 1934, only magnitude > 4 shocks can be accurately located; in 1966, shocks of magnitude > 2 shocks recorded between January 28, 1966, and June 30, 1966, are shown.

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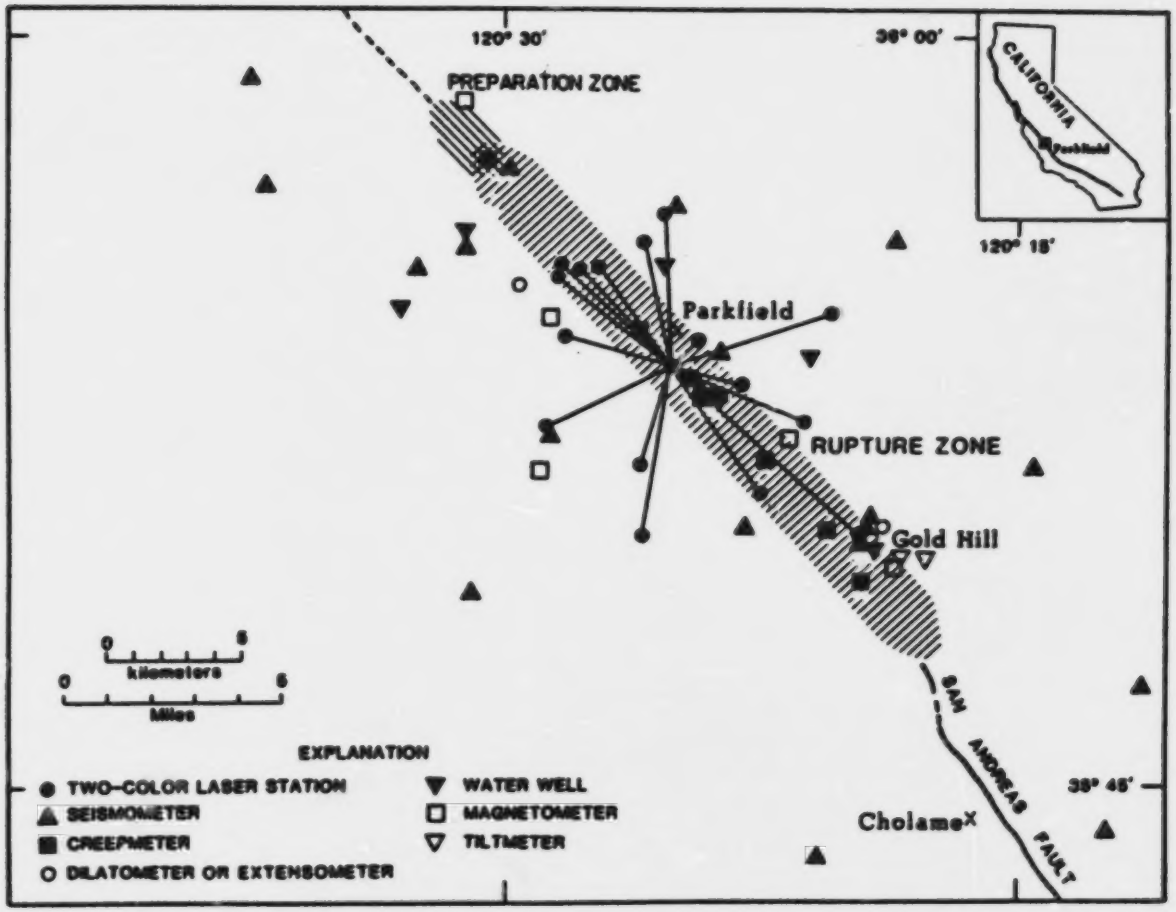

The Parkfield, California, earthquake prediction experiment. A cluster of seismometers, creepmeters, dilatometers, and other geophysical instruments arrayed about a central 2-color laser geodimeter, have been deployed along the San Andreas fault at Parkfield. The instruments are centered in the reach of the fault that is expected to rupture in a magnitude 6 earthquake sometime between 1965 and 1993, most likely in 1988.

Parkfield. These creepmeters can resolve a few fractions of an inch of anomalous fault slip and are well suited to detect premonitory slip of the magnitude that may have occurred in 1966.

Parkfield Earthquake Prediction Scenarios and Response Plans

It is the intention of the USGS to attempt to issue a short-term warning (minutes-to-days) of the anticipated shock based on observations of precursory phenomena recorded by elements of the prototype earthquake prediction network. Anomalous conditions have been defined that would change the assessment of the imminence of the expected earthquake and the action that would be taken by the USGS. A USGS planning document has been prepared that describes the conditions culminating in a communication (a Geologic Hazards Warning) from the USGS to the California Office of Emergency Services (OES). Responsibility for communicating these warnings to the public, to local governments, and to the press resides with OES.

Because viable deterministic models (if A occurs, then B *must* follow) of the earthquake process are not available, a probabilistic approach to earthquake prediction has been adopted. That is, the increased likelihood in the

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Parkfield, California,
Earthquake Prediction Experiment
Alert Levels

Alert Level	Response	Probability of Magnitude 6 Earthquake in Next 24 (72) hours	Anticipated Time Interval between Alerts
n (normal)	Continue normal operation	0.0001 to 0.0035	———
e	Alert project personnel; possible maintenance	———	———
d	Alert Parkfield Working Group and Data Collection Operations	0.0035 to 0.014 (0.0068 to 0.028)	2 mo. - 6 mo.
c	Alert Office Chief, and respond to Alert Level d.	0.014 to 0.059 (0.028 to 0.11)	6 mo. - 18 mo.
b	Alert Director, USGS, and Calif. State Geologist, Calif. Division of Mines and Geology and respond to Alert Level c.	0.059 to 0.22 (0.11 to 0.37)	18 mo. - 54 mo.
a	Issue Geologic Hazard Warning and respond to Alert Level b.	>0.22 (>0.37)	>54 mo.

Parkfield, California, earthquake prediction experiment alert levels.

near future of the anticipated shock will be assessed given the observation of anomalous conditions (*e.g.*, increased seismicity). Couching warnings in a probabilistic framework explicity allows for the possibility of warnings not followed in the near future by the anticipated shocks. For example, warnings will take the form "There is a 1 in 5 chance (0.22 probability) that the anticipated magnitude 6 shock will occur in the next 24 hours; the probability of the shock in the next 72 hours is at least 0.37."

If any of the four observational networks now monitoring the Parkfield area detect an anomalous state with respect to the normal background condition of the networks, then an alert will be indicated. If anomalous conditions are observed from more than one network, the level of the alert will be increased according to a set of formal rules. Preliminary alert level criteria have been established for each network type. Seismic alert criteria are based on estimates of the probability that an earthquake is a foreshock to the anticipated magnitude 6 event. The criteria for the other three network types are based on how frequently anomalous conditions are expected to occur and subjective estimates of the probability that an anomalous condition will precede a magnitude 6 shock at Parkfield.

Slip Deficit at Parkfield

A network of geodetic lines spanning the San Andreas fault near the rupture zone of the 1966

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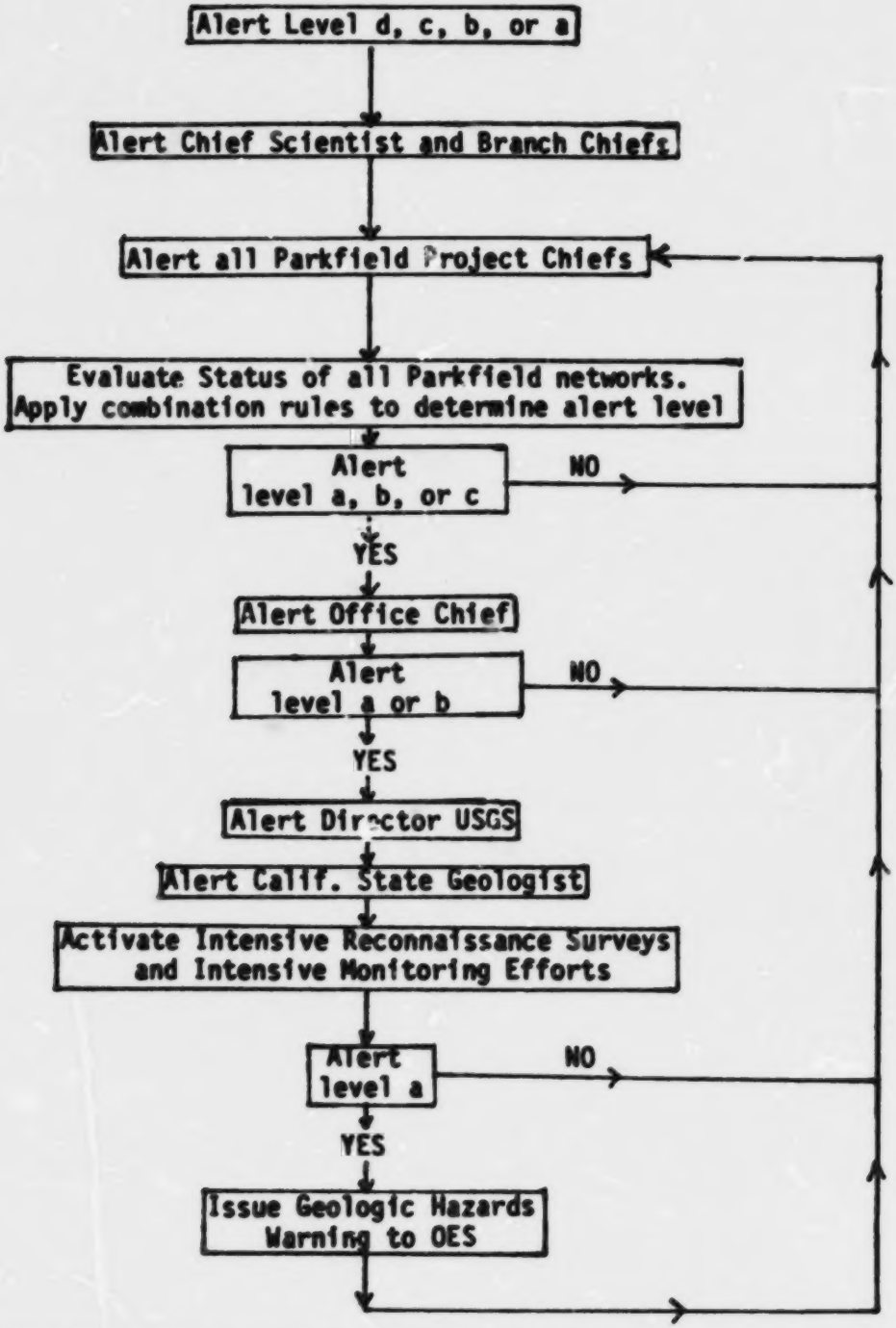
DECISION FLOW DIAGRAM


Alert Level d, c, b, or a
Alert Chief Scientist and Branch Chiefs
Alert all Parkfield Project Chiefs
Evaluate Status of all Parkfield networks. Apply combination rules to determine alert level
Alert level a, b, or c
NO
YES
Alert Office Chief
Alert level a or b
NO
YES
Alert Director USGS
Alert Calif. State Geologist
Activate Intensive Reconnaissance Surveys and Intensive Monitoring Efforts
Alert level a
NO
YES
Issue Geologic Hazards Warning to OES

Decision tree for the Parkfield, California, earthquake prediction experiment.

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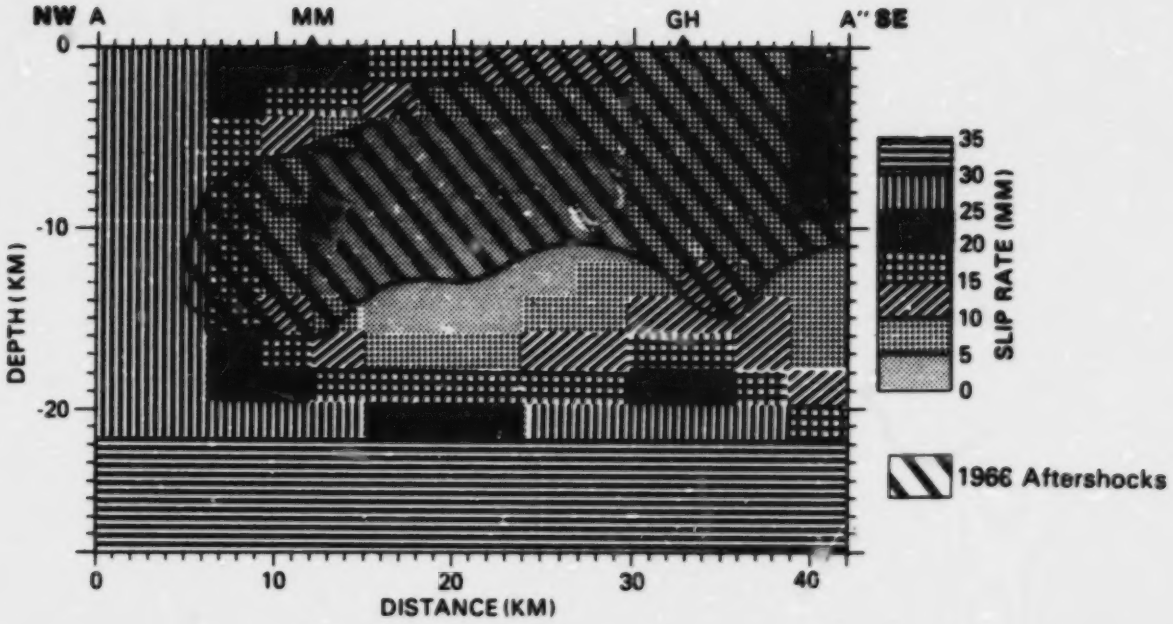

Interseismic-slip-rate pattern for the San Andreas fault at Parkfield inferred from inversion of geodetic data. In the model, slip occurs continuously on the San Andreas below a depth of approximately 22 kilometers (14 miles). Northwest of Parkfield, the shallow portion of the fault creeps at a rate of about 25 millimeters/year (1 inch/year); southwest of Parkfield, the fault is locked from the surface to the transition depth. A longitudinal cross section of the 1966 main shock (star) and its aftershocks (hachure) are projected onto the model fault. The model suggests that the fault is locked or nearly locked at intermediate depths, in the same area where the 1966 rupture occurred. MM is Middle Mountain, GH is Gold Hill.

Parkfield, California, earthquake has been repeatedly surveyed since 1959. The average rates of line-length change since 1966 were inverted to determine the distribution of the rate of interseismic slip on the fault. The results indicate that the Parkfield rupture surface has not slipped significantly since 1966. Comparison of the geodetically determined seismic moment of the 1966 earthquake with the interseismic-slip-deficit rate suggests that the strain released by the latest shock will most likely be restored by between 1984 and 1989, although this may not occur until as late as 1995. These results lend independent support to the earlier forecast of a magnitude 6 earthquake near Parkfield within five years of 1988.

Earthquake Prediction Workshops

Since early 1985 the USGS, in conjunction with the National Earthquake Prediction Evaluation Council (NEPEC), has held a series of workshops that have considered the major plate boundary faults of California and Alaska. The purpose of these meetings has been to identify those areas of high, long-term seismic potential where further geological, geophysical, and seismological research is needed and where intensified earthquake prediction monitoring is merited. In several instances, working groups of interested scientists were formed to frame recommendations for new work, meet periodically, and monitor changing seismic conditions in specific regions.

In California, the point of departure of these studies has been the several recent assessments of long-term earthquake potential of major strands of the San Andreas fault system. These independent assessments differ in details of interpretation; however, their conclusions are derived from basically the same historic and prehistoric seismic data, supplemented by other geological and geophysical observations, and so the probability estimates are quite similar.

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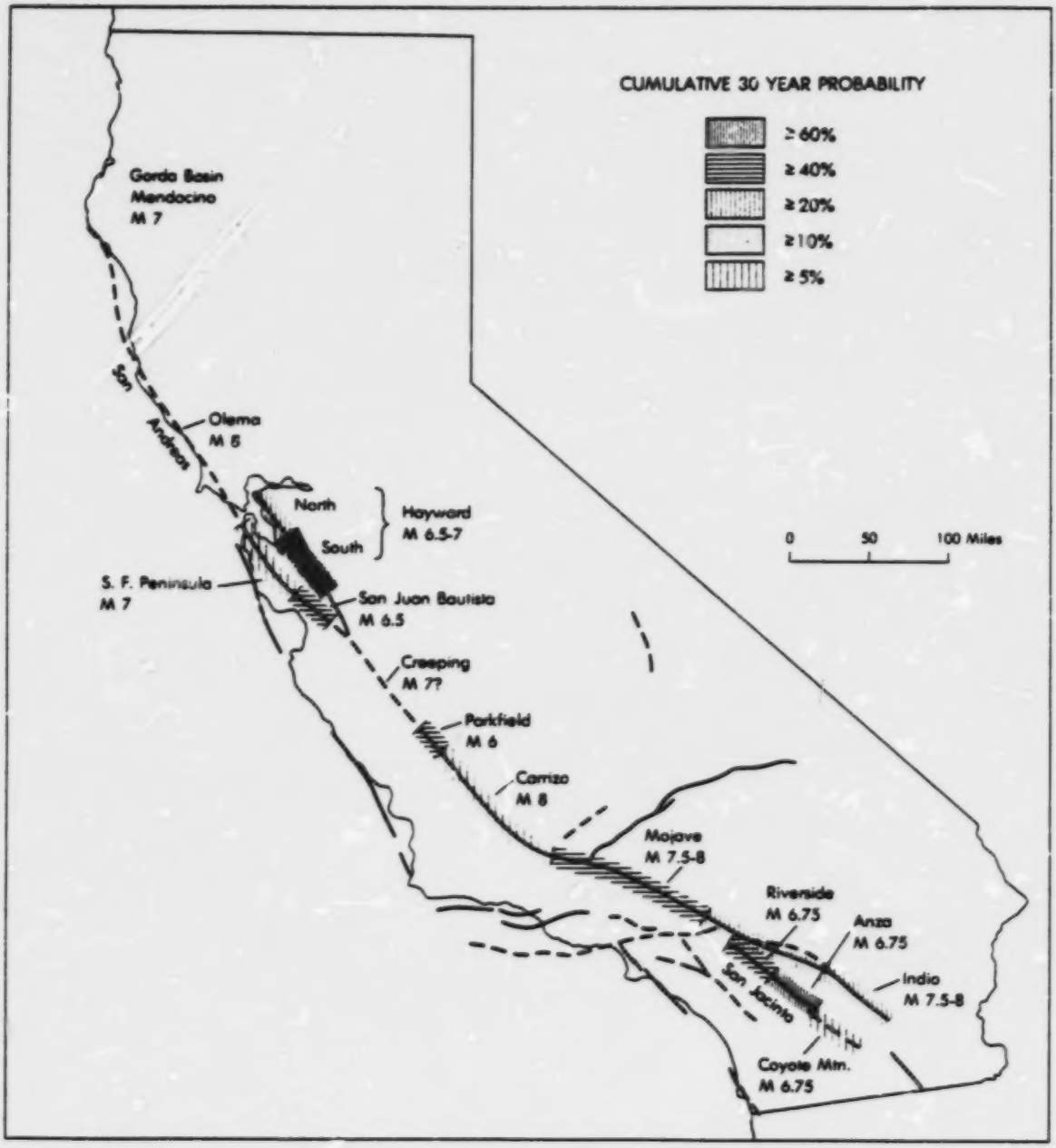

Cumulative 30-year probability for earthquakes on the San Andreas fault system.

In both California and Alaska the model for intensified observations has been the Parkfield earthquake prediction experiment: a focused monitoring program employing densely-spaced networks of seismic, geodetic, and borehole strain sensors dedicated to real-time surveillance. However, none of the areas pinpointed for intensified observation are as yet so well-understood as the Parkfield region. In several regions, further geologic studies are especially required to determine earthquake recurrence intervals. In other areas, geodetic

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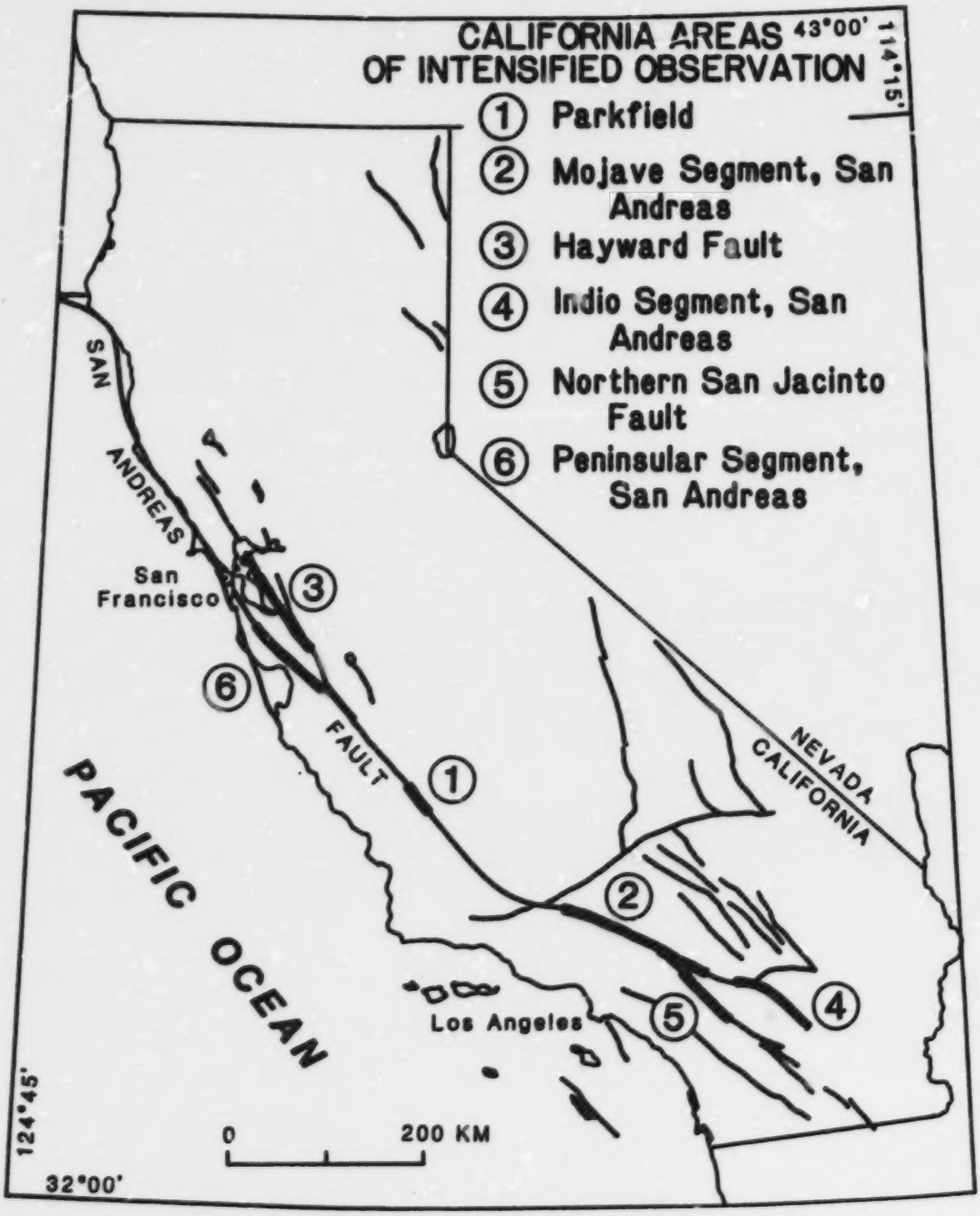

Six segments of the San Andreas fault system have been recommended for intensified earthquake prediction study.

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survey networks must be established or densified in order to define the detailed patterns and rates of strain buildup. Many of the prediction monitoring strategies developed at Parkfield have obvious applications elsewhere. At the same time, conditions peculiar to each area indicate the need for especially tailored experiments that account for factors such as logistical constraints, local fault features, and the extent of the region under surveillance.

Six fault segments were recommended for intensified study. They include (listed roughly in order of decreasing priority):

1. Parkfield: High probability of a magnitude 6 earthquake in 1988 ± 5 years.
2. Mojave segment: Part of the San Andreas fault ruptured in great 1857 earthquake in a zone where paleoseismic evidence indicates average recurrence of 145 years.
3. Hayward fault: Ruptured in magnitude 7 earthquakes in 1838 and 1868. Recurrence interval and strain accumulation characteristics poorly understood, but fault traverses densely-populated region and seismic potential could be high.
4. Indio segment: No historic large earthquake on this section of San Andreas fault, but slip rate is probably about 1 inch/year and paleoseismic evidence suggests an event at approximately 1700 A.D.
5. Northern San Jacinto fault: Long-term slip rate of about 0.4 inches/year and although much of this 75-mile-long segment ruptured in a series of magnitude 7 events during 1890-1923, two zones of seismic slip deficit have been identified. Furthermore, sufficient strain may have accumulated in the past 50 or more years to re-rupture the remainder of this zone. New information on recurrence intervals needed on this fault segment.
6. Peninsular San Andreas. 50-mile-long segment where observed surface slip in great 1906 earthquake was less than that to the northwest on the fault. Opinion is divided on reliability of surface slip estimates, which are significantly less than those determined geodetically, and the seismic potential estimates depend critically on the magnitude of the slip occurring at seismogenic depths.

In addition to these six regions, an additional 13-mile-long segment of the Calaveras fault, the "Alum Rock gap," near San Jose, California, may have a high intermediate term (about 5 years or less) seismic potential: two segments immediately to the southeast ruptured in magnitude 6 earthquakes in 1984 and 1979 respectively and some historic data suggest that the magnitude 6 zones and the Alum Rock gap each ruptured last during 1897-1911.

Two seismic gaps in the Alaska-Aleutian arc have been pinpointed for more study:

- Yakataga gap: 125-mile-long plate boundary segment in eastern Gulf of Alaska unruptured since at least 1899. Geodetically-measured strain accumulation shows maximum contraction axis alined in a direction of plate convergence.
- Shumagin gap: 190-mile-long arc segment which has experienced large local tsunamis in historic time but has not sustained seismic rupture since at least 1899-1903. However, the absence of detectable strain accumulation in the Shumagin Islands at the present time suggests the possibility of contemporary aseismic subduction in this region.

SEISMIC DESIGN AND ENGINEERING RESEARCH

Engineering Seismology

The Engineering Seismology Element of the USGS Earthquake Hazards Reduction Program is responsible for (1) the coordination and operation of the National Strong Motion Network to collect, process, and disseminate earthquake strong-motion data; and, (2) the development of improved methodologies to estimate and predict earthquake ground motion. Instrumental observations of strong ground shaking induced by damaging earthquakes and the corresponding response of man-made structures provide the basis for estimating the severity of shaking from future earthquakes, for earthquake-resistant design, and for understanding the physics of seismogenic failure in the Earth's crust. The data are utilized by researchers in the earth-science and engineering communities, and by architects and design engineers for design of buildings, bridges, and critical facilities such as dams and nuclear power plants.

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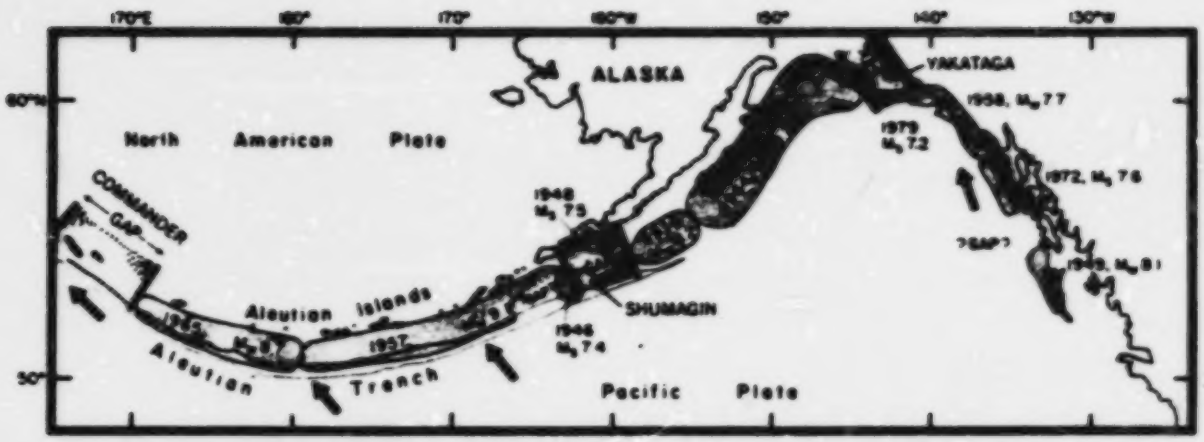

Rupture areas of large, shallow earthquakes along the Alaska-Aleutian arc from 1938 to 1979. The heavy arrows denote motion of the Pacific plate relative to the North American plate. Seismic gaps, where large or great earthquakes may occur in the next several decades, are shaded.

Responsibility for the National Strong Motion Network, a network of instruments designed specifically to record strong earthquake ground shaking, was transferred to the USGS from the National Science Foundation in Fiscal Year 1983. The Network has been expanded to approximately 1,000 strong-motion accelerographs designed to record ground motion and structural response near the source of damaging earthquakes. These instruments are located in the seismically active regions of the United States. The network is a cooperative effort involving many organizations including principally the USGS, the U.S. Army Corps of Engineers, the Veterans Administration, the Metropolitan Water District of Southern California, and the California Department of Water Resources.

The USGS also has developed and maintains field-portable General Earthquake Observation System (GEOS) instruments to record ground motions over a wide frequency band and dynamic range. The capability of the GEOS recording system to record over a wide range in amplitude and bandwidth allows for a broad range of applications, including strong ground motions near fault ruptures, high-frequency seismology near small earthquake events, and low-frequency studies of Earth strain. This capability has been used most extensively in the study of the earthquake aftershock sequences in the Western United States. It has also been used in investigations after major earthquakes in Chile and Mexico in 1985. Recently these instruments have been deployed in the Eastern United States to study earthquake characteristics and wave-propagation phenomena at Monticello Reservoir, South Carolina; near Enola, Arkansas; in southern Maine; at Miramichi, New Brunswick (Canada); and near Painesville, Ohio. The results of the field studies in the Eastern United States challenged traditional ideas about ground motion in eastern North America and contributed to the development of improved methods of ground-motion prediction.

USGS seismologists are gaining new insights into the earthquake rupture processes by analysis of data from the Anza seismic network, a high-dynamic range seismometer array with digital telemetry located near a segment of the San Jacinto fault in California. That segment of the fault has not ruptured in this century and is considered to have a high probability for an earthquake of magnitude 6 within the next 30 years. The high quality of the data from this network permits delineation of complex details of rupture for earthquakes of magnitude (M_L) about 3. Strong-motion instruments are included in the network so that similar analysis will be possible for large earthquakes.

The USGS is preparing to install a dense array of seismographs on the surface and in boreholes near Parkfield, California, to record the moderate-size earthquake predicted to

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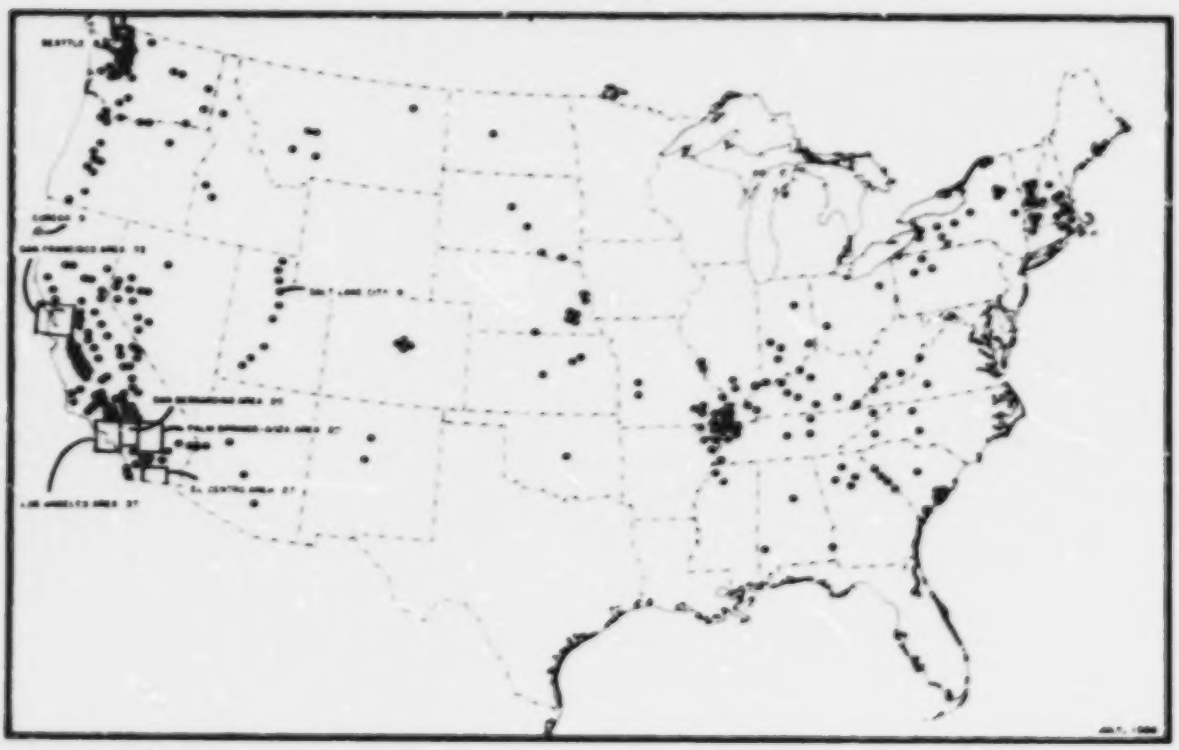
occur within the next several years on the central San Andreas fault near Parkfield. Analysis of the dense-array data will permit seismology to trace the development of the fault rupture as it spreads out over the fault plane from its point of inception, yielding a deep understanding of the rupture process and an improved ability to predict ground motion.

Engineering Seismology research contributes in an important way toward earthquake hazard reduction through earthquake provisions of building codes. Building codes in the United States are legislated by local government, but the provisions are written by professional engineering associations. USGS scientists and engineers are active on the code-writing committees of the Structural Engineers Association of California (SEAOC) and are participating in the current revision of the SEAOC publication *Recommended Lateral Force Requirements*, which is proposed as the basis of the earthquake provisions of the 1988 Uniform Building Code.

Borehole Seismology

A key element in predicting ground motion in future earthquakes is estimating the effect of the near-surface materials on ground motion at a site. To better understand this effect, USGS scientists are generating artificial seismic waves at the surface of the ground and recording those waves on seismometers in shallow boreholes to determine the seismic wave velocity and the attenuation properties of the near-surface materials. A new seismic shearwave generator has been developed for this work by USGS scientists. It is powered by compressed air and generates highly reproducible shear-wave signals with substantially greater amplitude than could be obtained with earlier devices. Shear-wave velocity and attenuation were measured to a depth of more than 400 feet using the new device in a borehole at a site where ground motion was measured in aftershocks of the 1983 Coalinga, California, earthquake.



National Strong Motion Network stations, operated by the USGS in cooperation with other agencies.

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A shear-wave generator, driven by compressed air and used to produce artificial seismic waves for borehole measurement of velocity and attenuation properties of near-surface materials. The weight of a truck is used to hold the shear-wave generator in contact with the ground. The compressed-air hose is not attached in this picture.

Ground Motion in the Eastern United States

Relatively few earthquakes occur in the Eastern United States. On average, only 1 to 2 earthquakes of magnitude ≥ 4 occur annually east of the Rocky Mountains. Although uncommon, the earthquakes can be severe. Three great earthquakes, plus hundreds of damaging aftershocks, occurred near New Madrid, Missouri, in 1811 and 1812. One century ago, a large earthquake centered near Charleston, South Carolina, caused extensive damage to the city and numerous surrounding towns. Because earthquakes are less frequent than in the Western United States, far fewer strong-motion recordings of Eastern earthquakes are available. Predicting ground motion in future Eastern earthquakes consequently is much more difficult than in the West. Ground-motion predictions have been made for the Eastern United States using a theoretical model developed by USGS seismologists. This model has been highly successful in explaining strong ground motions recorded in Western United States earthquakes as well as weak motions recorded from distant great earthquakes worldwide. The model was applied to the Eastern United States using the limited available data to evaluate model parameters, and ground-motion predictions were made at magnitudes and distances for which no data are available.

Earthquake Structural Response

Strong-motion instruments are placed in structures to gain understanding of the behavior of structures under seismic shaking. Very few records have been obtained that show structural response at damaging levels of ground motion. For that reason the set of records obtained in

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Strong-motion instrumentation is being installed in seismically active regions across the United States and in Puerto Rico to record and analyze building structural response to earthquake shaking.

1979 from the severely damaged 6-story Imperial County Services Building in El Centro, California, are extremely valuable. More are needed. The ultimate benefit will be improvements in structural design and in the seismic provisions of building codes.

The USGS structural instrumentation program has proceeded since 1983 under a policy of working through local advisory committees established in seismically active regions. The committees, which consist of practicing engineers, university faculty members, and State and local government officials, make recommendations on the structures to be instrumented and the placement of instruments in the structures. The program is active in Alaska, Hawaii, California, Washington, Nevada, Montana, Missouri, South Carolina, Massachusetts, and Puerto Rico. New instrumentation is being installed this year in California and South Carolina, and preparations are being made in Alaska, Massachusetts and Missouri.

FUNDAMENTAL SEISMOLOGICAL STUDIES

Data and Information Services

The USGS National Earthquake Information Center (NEIC) in Golden, Colorado, is responsible for the operation of the global seismograph networks and for processing of seismic data from these networks. The NEIC provides rapid and accurate earthquake epicenter determinations, as well as other seismic data and information to government, universities, private research groups, and the general public.

Global Seismograph Networks

Global seismograph networks catalog the thousands of earthquakes that occur worldwide each year. The networks provide the data needed for detailed studies of earthquake mechanisms, deep Earth structure, and tectonic

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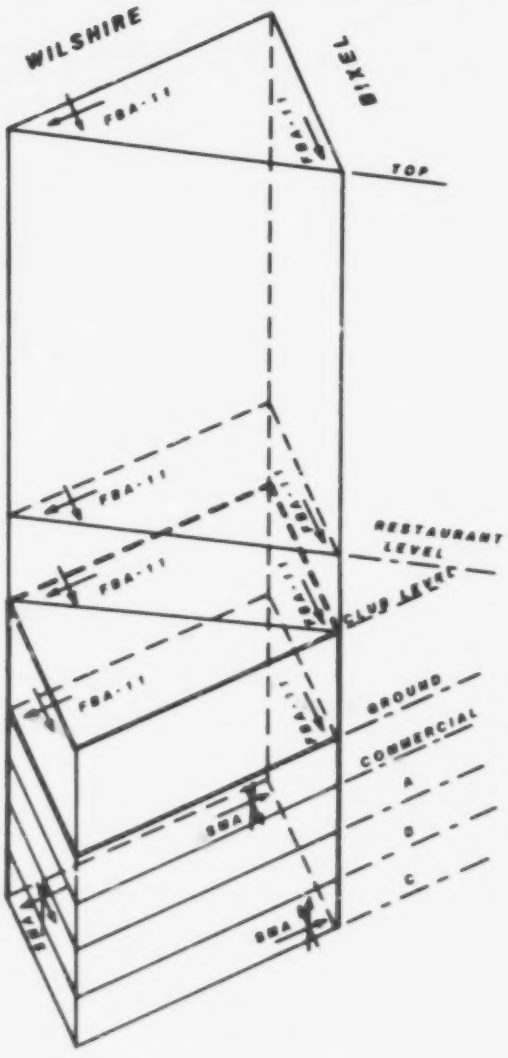

The new Wilshire Finance Building in downtown Los Angeles was recently instrumented to record its motion during future earthquakes. The sensors are force-balance accelerometers and strong-motion accelerographs. The sensor locations ere selected to determine the lateral, torsional, and rocking motions of the structure as well as to evaluate the effect of the abrupt change in the building's cross section from a square shape in plan (lower floors) to a triangular shape upper story.

processes. The USGS supports the operation of two global networks: the Worldwide Standardized Seismograph Network (WWSSN) and the Global Digital Seismograph Network (GDSN). In Fiscal Year 1986, the USGS also assumed responsibility for a seismic array in Wyoming previously operated by the Air Force.

World-Wide Standardized Seismograph Network

The WWSSN was established in the early 1960's as part of Project Vela Uniform, a program of fundamental and applied research in seismology directed toward solving Comprehensive Test Ban Treaty monitoring problems. Key elements of the WWSSN are standardized three-component, long- and short-period, uniformly calibrated seismographs, and the means for distributing seismograms to the earthquake research community. The WWSSN today comprises about 100 stations operating in 54 countries; this network continues to produce data very useful for fundamental research in seismology. The responsibility for managing the WWSSN was transferred from the U.S. Coast and Geodetic Survey (USCGS) in 1973 to the USGS; since 1978 the network has been funded entirely by the USGS under its Earthquake Hazards Reduction Program. Since the inception of the WWSSN, more than 5 million original seismograms have been microfilmed, and 60 million high-quality film copies have been supplied to research workers. Despite the superiority of the more recently available digital seismic data for many purposes, the analog seismograms from WWSSN remain the foundation for much fundamental seismological research, not only in the United States, but also around the world. The contribution of WWSSN data to global tectonics theories has been great.

Global Digital Seismograph Network

The USGS also operates the GDSN, which provides extremely high quality digital seismic data for seismological research and is a unique international information resource. Digital recording provides much greater resolution and recording range than analog recording, and the data are available in a format suitable for computer processing and analysis.

Global Seismological Research

Digital data from not only the USGS-operated global network (the GDSN), but also from other high quality international seismic networks are made available to the national and international scientific community by the NEIC. To accomplish this data distribution, the NEIC continues

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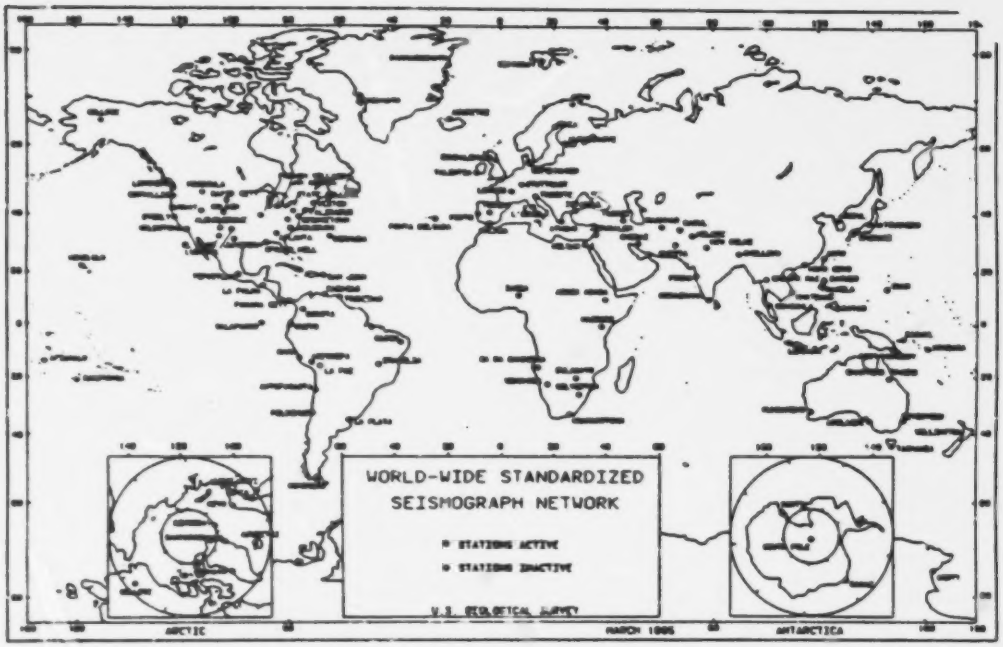
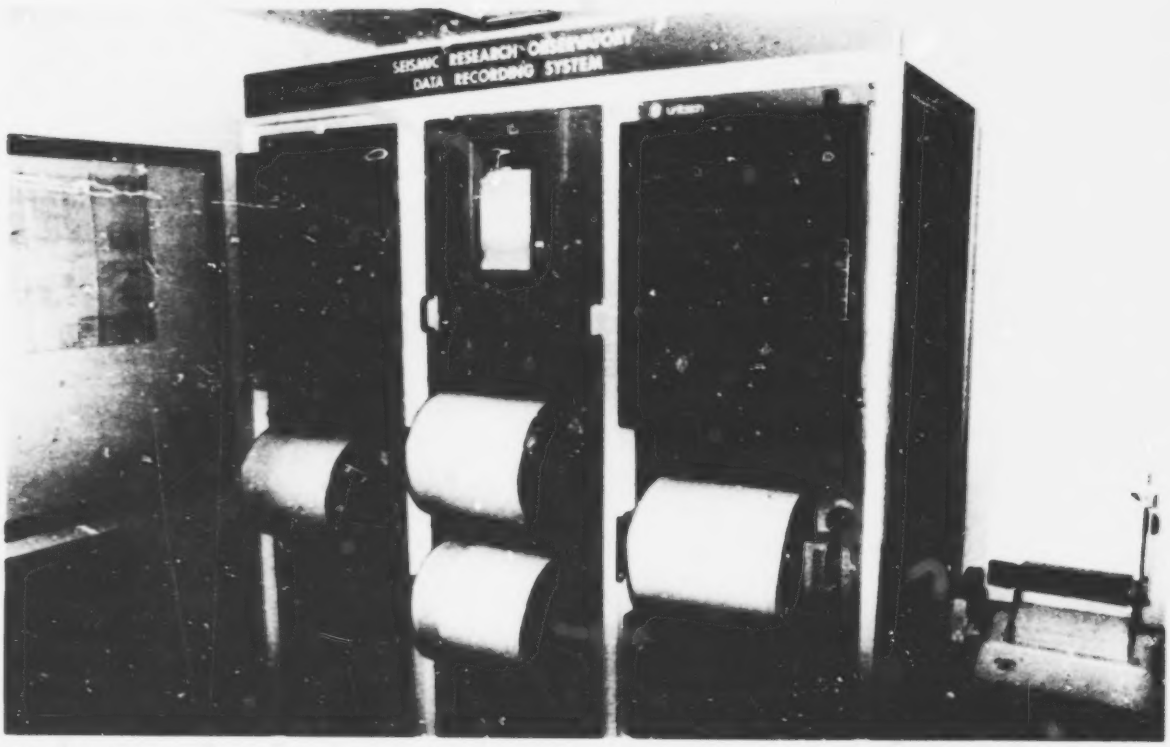


Worldwide Standardized Seismograph Network



The data recording system of one of the Seismic Research Observatory (SRO) stations of the USGS Global Digital Seismograph Network.

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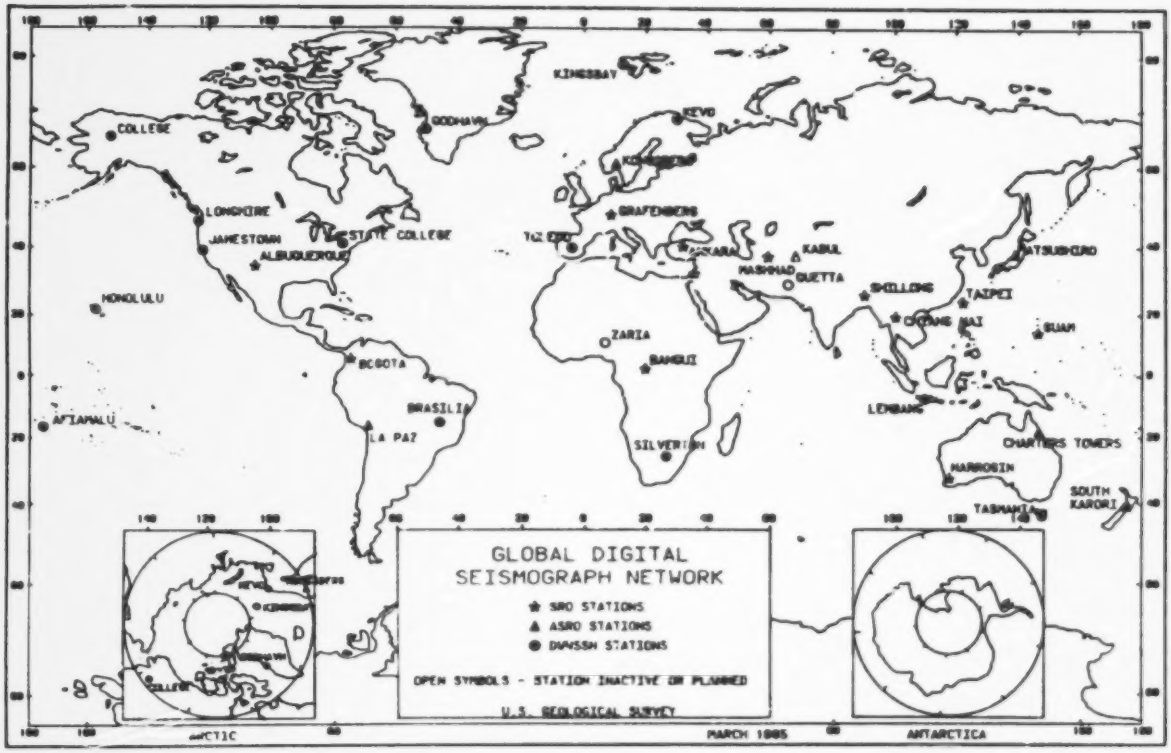

Global Digital Seismograph Network.

an active program of investigation and use of state-of-the-art computer storage and management systems. The NEIC has become a major National Seismic Data Center for the United States. Research activities include studies of plate tectonics, Earth structure, and earthquake source mechanisms. This observational research is critical to the verification of theoretical hypotheses in all areas of seismology.

The NEIC also carries out research on the internal structure of the Earth and its effects on earthquake location and severity, seismicity patterns related to the occurrence of large earthquakes, and on the specifications of earthquake sources. Detailed earthquake source mechanisms are now routinely being reported by the NEIC in the form of moment tensor solutions. The NEIC is the foremost collector of earthquake data from around the world, including data from the People's Republic of China and the Union of Soviet Socialist Republics.

National Earthquake Information Service

The NEIC also has responsibility for the operation of the Earthquake Early Alerting Service (EEAS) and for publication of earthquake data recorded by the global networks. This responsibility is carried out through the National Earthquake Information Service (NEIS). The EEAS is manned 24 hours a day. The NEIS determines the location and magnitude of significant earthquakes in the United States and around the world as rapidly and as accurately as possible, and communicates this information to appropriate authorities. The information is given to Federal and State government agencies that are responsible for emergency response, to government public information channels, to the national and international news media, to scientific groups (including groups planning earthquake aftershock studies), and to private citizens who request information.

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Quick Epicenter Determinations (QED) of earthquakes recorded by the global networks are calculated daily. Computerized QED hypocenter information is available to computer-users worldwide through a toll-free telephone portal (*800-358-2663*) to the Golden, Colorado, NEIS center. A weekly *Preliminary Determination of Epicenters (PDE)* distributed by the NEIS lists the location, magnitude, and felt effects of an average of 100 or more earthquakes that are recorded and located weekly by the global networks. The monthly *PDE* and the accompanying *Earthquake Data Report* summarizes monthly worldwide earthquake activity, including many additional earthquakes for which there were insufficient data to be published in the weekly *PDE*. Approximately 7,000 earthquakes per year are listed in the *Monthly Listing* and the *EDR*. These publications have worldwide distribution, including the scientific community, many in the business world, educational institutions, and the general public. The *Monthly Listing* is available by subscription through the U.S. Government Printing Office.

Seismogram Project

Responsibility for the seismogram microfilming project for WWSSN data was transferred to the NEIC from the National Geophysical Data Center (NGDC)/National Oceanic and Atmospheric Administration in Fiscal Year 1985. Each year more than 300,000 analog seismograms from about 150 seismograph stations worldwide are microfilmed and archived, adding to this file that now contains more than 5 million records. Records are available to researchers from (1) WWSSN and GDSN stations; (2) the Canadian Seismograph Network (a 28-station network); and (3) the People's Republic of China Network (which includes 17 stations).

The NDGC Historical Seismogram project was also transferred to the NEIC/USGS. The film archive of Historical Seismograms contains more than one-half million pre-1962 records for selected earthquakes and stations. This project preserves and archives historically important seismographic records for future researchers. The archive now contains film copies of all available records from nine stations in the United States, Japan, and Puerto Rico, as well as selected events from nine additional U.S. stations. These data are available on 16- and 35-millimeter film, or researchers may review many of the original seismograms.

FOREIGN INVESTIGATIONS

The USGS participates in foreign earthquake investigations and in a number of international cooperative projects in observational seismology, studies of strong ground motion, and earthquake prediction to accelerate and enhance earthquake research in the United States.

1985 Mexico Earthquake

On September 19, 1985, central Mexico was severely shaken by a great, magnitude (M_s) 8.1 earthquake. The earthquake was centered about 25 miles off the west coast of Mexico, near the town of Lazardo Cardenas, Michoacan. Shaking was reported as far away as southern Texas. Remarkably, damage in the epicentral area was minor; several structures in Ixtapa were reportedly damaged. In the densely populated central district of Mexico City, 250 miles northeast of the epicenter, damage to multi-storied buildings (5 to 21 stories) was severe. More than 1,000 medium- and high-rise buildings were severely damaged or destroyed, many collapsing to the street below. At least 8,000 people were killed; 30,000 injured (10,000 of these were injured seriously); and nearly $5 billion in property destroyed.

The USGS and the National Bureau of Standards sent a joint team of engineering seismologists and structural engineers to Mexico City immediately after the earthquake to gain insight into the cause of the unusual damage. The Mexico earthquake is similar to the great earthquakes that occur in southern coastal Alaska and in Puerto Rico, and that may occur in the Pacific Northwest. Later, in January 1986, the USGS sent a second team to Mexico City to perform site-response and structural vibration studies.

The teams determined that the extraordinary high degree of damage in Mexico City was mainly due to amplification of the long-period ground motion by the 160-foot thick, water-saturated ancient lakebed that underlies part of

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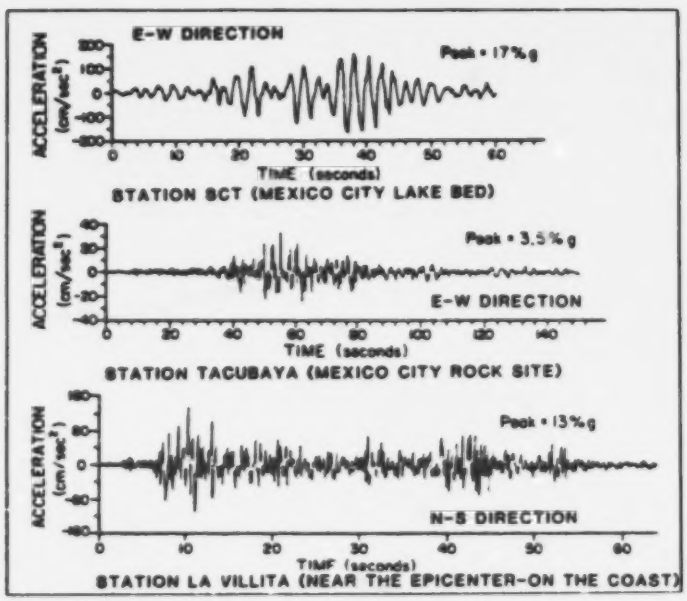
Shortly after dawn, Thursday, September 19, 1985, Mexico City was rocked by a severe earthquake. The unconsolidated lake sediments beneath Mexico City amplified the ground motion by about a factor of 5, causing the ground to shake at the natural resonances of medium- and high-rise buildings. Over 450 buildings collapsed or were totally destroyed; 600 others were seriously damaged.



Strong-motion acceleration records of the 1985 Mexico earthquake. The peak accelerations of ground motions at Mexico City on sites underlain by volcanic rock were 0.03 g, attenuated from peak values of 0.14 g at the epicentral region, 250 miles southwest of Mexico City. The ground motions were amplified by the lakebed beneath Mexico City: peak accelerations reached 0.17 g; resonating spectral peaks reached 1.0 g (5% damping) at the dominant 2.0 second period of the lakebed zone.

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Mexico City. The lakebed had been recognized in 1964 as having a characteristic site period of about two seconds, the natural period of vibration of a 20-story building. Coastal earthquakes in 1957 and 1962 had also caused damage in Mexico City that was attributed to site amplification. Structures with dominant periods in the range of the dominant period of the local site were shaken intensively during the 1985 earthquake. Those structures with proper foundations and sufficient ductility were able to withstand the long resonant shaking. Others either collapsed or were heavily damaged, tilted, settled, or pounded against adjacent structures.

RESEARCH IMPLEMENTATION

The USGS, in cooperation with FEMA and other Federal Agencies, convened six workshops in Fiscal Year 1986 to foster State and local implementation of measures to reduce earthquake hazards in earthquake-prone areas of the United States. Workshops were held in Seattle, Washington; San Francisco, California; Los Angeles, California; Nashville, Tennessee; San Juan, Puerto Rico; and Salt Lake City, Utah. The meetings were part of a series of 26 regional workshops that have been held since Fiscal Year 1978. The workshops are designed to:

- Establish partnerships with Federal, State, and local governments and private institutions in the United States;
- Identify local expertise in every part of the Nation, stimulate interested people to accelerate their learning about earthquake hazards, and foster the implementation of seismic safety policies; and
- Communicate research results and information on earthquake hazards and risk to various users, including Federal agencies, State and local governments, engineers and scientists engaged in research and design, professional organizations, model building code groups, and emergency management specialists.

The workshops have brought together scientists and representatives from all levels of government, academia, and the private sector to (1) review the state of knowledge of the local earthquake hazard; (2) determine the need for additional scientific, engineering, and societal-response information to implement effective earthquake hazards loss-reduction programs; and (3) create practical plans for achieving hazards reduction. The meetings have proved to be important catalysts in the successful mitigation of earthquake hazards, and have resulted in the formation of several regional seismic safety commissions.

WORKSHOP ON "EARTHQUAKE HAZARDS IN THE PUGET SOUND, WASHINGTON, AREA," OCTOBER 29-30, 1985

A group of 85 geologists, seismologists, engineers, social scientists, emergency planners, and public officials met in Seattle, Washington, on October 29-30, 1985, to discuss earthquake planning and preparedness in the Puget Sound area. More than 1,000 felt earthquakes have occurred in the area since pioneers first settled in the Pacific Northwest 140 years ago. A number of the shocks have been of moderate to large magnitude. A magnitude 7.0 earthquake near Olympia, Washington, in 1949 killed eight persons and caused more than $80 million in property damage (in 1979 dollars). A magnitude 6.5 earthquake in 1965 in Seattle, Washington, resulted in seven deaths and $28 million in property damage (in 1979 dollars).

The workshop was sponsored by the USGS, FEMA, the Washington State Department of Natural Hazards, and the Washington State Department of Emergency Management. Workshop participants reviewed the current understanding of the earthquake hazards of the Pacific Northwest and assessed State and local measures to reduce the hazards. A number of the speakers noted that a considerable body of information on the earthquake hazards of the Puget Sound area already exists. However, the seismologists and geologists at the workshop pointed out that a suitable tectonic explanation for the occurrence of earthquakes in the Pacific Northwest — particularly why most earthquake activity in the region has been localized in the Puget Sound area — has not yet emerged from the continuing seismic studies of the region. The scientists emphasized that additional knowledge is needed to resolve whether a great earthquake similar to the 1960 Chile earthquake or 1985 Mexico earthquake might occur in the

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Puget Sound area. A growing number of scientists suspect that the Juan de Fuca and Gorda plates, which plunge beneath western Washington, Oregon, and northern California, may be strongly coupled with the North American plate. Although there is a paucity of present-day seismicity (as well as significant historic activity) in the shallow part of the subduction zone near the coast, moderate magnitude, deep-focus earthquakes apparently on the surface of the subducting Juan de Fuca plate occur beneath Puget Sound.

The workshop participants agreed that highest priority should be given to studies of:

- Historical seismicity.
- Seismogenic sources (including the Cascadia subduction zone).
- Earthquake recurrence.
- Tsunamis.
- Attenuation law for spectral velocity.
- Local ground response and soil-structure interaction.
- Engineering properties of soil and rock.
- Regional liquefaction susceptibility.
- Regional landslide susceptibility.

The group also recommended several loss-reduction measures, including

- Maps of seismogenic zones.
- Maps of expected ground shaking.
- Reports on engineering properties of soil and rock.
- Maps of regional liquefaction susceptibility.
- Education programs.
- Preparation of model codes and land-use plans.

The participants called for another meeting to further accelerate progress in earthquake hazards mitigation and reduction in the Puget Sound area. The group urged that high priority be given to the planning of a Seismic Safety Council in Washington.

"WORKSHOP ON FUTURE DIRECTIONS IN EVALUATING EARTHQUAKE HAZARDS IN SOUTHERN CALIFORNIA," NOVEMBER 13-14,1985

In November 1985, the USGS published a comprehensive new review of the earthquake hazards of the Los Angeles region, California. The new publication, *Evaluating Earthquake Hazards in the Los Angeles Region — An Earth-Science Perspective* (USGS Professional Paper 1360), describes state-of-the-art methods for evaluating geologically controlled earthquake hazards as a basis for reducing future losses. A special workshop was convened in Los Angeles by the USGS, FEMA, the National Science Foundation, the California Division of Mines and Geology, and the California Office of Emergency Services, to highlight the new advances in earthquake hazards reduction in southern California, and to assess future directions in the production and use of geological and seismological information for reducing geologic hazards in the southern part of the State.

About 330 people attended the two-day workshop. Participants included specialists from the Earth sciences, social science, land-use planning, engineering, emergency management, public administration, law, public health, insurance, and real estate. Numerous private firms; universities; public utilities; and Federal, State, and local units of government were also represented. The multidisciplinary workshop was highlighted by summaries of key results of recent scientific research on the earthquake hazards of the Los Angeles region, and by examples of local earthquake hazards reduction efforts. The workshop concluded with general discussions of (1) what additional scientific and technical information is needed for reducing earthquake hazards; and (2) which hazard-reduction strategies are most effective and how can they be improved?

WORKSHOP ON "PROBABILISTIC EARTHQUAKE HAZARDS ASSESSMENTS," NOVEMBER 25-27, 1985

The USGS and the Nuclear Regulatory Commission jointly convened a three-day technical workshop on probabilistic earthquake

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hazards assessments in San Francisco, California, in late November 1985. The workshop's objectives included: (1) a review of methodologies currently used to assess earthquake hazards probabilistically, especially in the Eastern United States; and (2) indentification of practical and innovative ways to improve the overall state-of-knowledge and to foster improved communication and utilization of this fundamental knowledge in the siting of nuclear power reactors and other applications.

Forty-five scientists and engineers from the United States and foreign countries attended the workshop. In four successive sessions, the workshop participants reviewed the characterization and representation of earthquake hazards and risk, and the methodologies currently used for probabilistic hazards assessment. The participants concluded that although significant progress had been made in the past decade, great care must be taken to ensure:

- A concentrated effort to eliminate or resolve critically important technical issues that now contribute substantially to the present controversy associated with the ground-shaking hazard.
- Wise use of probabilistic models.
- Cross education of geologists, geophysicists, seismologists, and engineers.
- Increased understanding of the physics of the earthquake generation process.
- Incorportion of more physics and mechanics into the analytical models.

"WORKSHOP ON EARTH SCIENCE CONSIDERATIONS FOR EARTHQUAKE HAZARDS REDUCTION IN THE CENTRAL UNITED STATES," NOVEMBER 25-27, 1985

Sixty-six earth scientists, engineers, planners, and emergency management specialists gathered in Nashville, Tennessee, on November 25 to 27, 1985, to assess the availability of technical information needed for adoption of earthquake hazards mitigation and response measures by public and private institutions in the Central United States. The workshop, which was cosponsored by the USGS, FEMA, the Tennessee Emergency Management Agency, and the Central U.S. Earthquake Preparedness Consortium, was the third in a continuing series of conferences and workshops that have been held since 1981 to reduce losses from earthquakes in the Mississippi Valley area and surrounding States. The Central United States has experienced several of the largest earthquakes to occur in the United States. Between December 1811 and February 1812, the area was rocked by three great earthquakes centered near New Madrid, Missouri. The tremors caused extensive disruption on the land over a vast region between the confluence of the Ohio and Mississippi Rivers on the north and Memphis, Tennessee, on the south. Shaking was felt over an area of about 21 million square miles; doors and windows rattled in Washington, D.C.; in Boston, church bells rang from the shocks.

The workshop participants were asked to review the most up-to-date technical information available for hazard reduction and to identify the kind of information and research needed to improve the capability of emergency planners to protect lives and property in the Central United States. The group concluded that sufficient scientific and technical data were already available to start implementation of loss-reduction measures. The group also recommended several measures to increase the use of existing technical information.

WORKSHOP ON "ASSESSMENT OF GEOLOGIC HAZARDS AND RISK IN PUERTO RICO," MAY 14-16, 1986

The USGS, FEMA, the Puerto Rico Department of Natural Resources, the Puerto Rico Planning Board, and the Puerto Rico College of Engineers cosponsored a workshop on "Assessment of Geologic Hazards and Risk in Puerto Rico" in May 1986. The workshop, the third hazards workshop in Puerto Rico since 1984, addressed both the earthquake and landslide hazards of the Commonwealth. Sixty-five participants discussed the current earthquake vulnerability study of San Juan and the new Puerto Rico building code. Several engineers and scientists reviewed the catastrophic 1985 earthquakes in Mexico and Chile and assessed their implications to building design and safety in Puerto Rico. The workshop

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also included a review of the 1985 Mameyes, Puerto Rico, landslide disaster, and plans to reduce the island's escalating landslide losses.

The workshop participants formulated a multidisciplinary task force to upgrade the level of geologic, engineering, and seismological information needed for geologic hazards reduction programs in Puerto Rico. At the close of the workshop, Alejandro Santiago Nieves, the Secretary of the Puerto Rico Department of Natural Resources, urged the establishment of a non-partisan commision to recommend to the Governor and Legislative Assembly of Puerto Rico a program of action to:

- Establish a high-level advisory council to consider all aspects of natural-hazard mitigation.
- Develop a program of studies and research designed to fill existing gaps in knowledge about geologic hazards events.
- Design and implement a program of public awareness, involving all levels of society and all economic sectors.
- Estimate the resources required to implement a long-term program of hazards reduction, and obtain a legislative commitment for funding, with possible supplemental funding from foundations, Federal programs, and the private sector.

WORKSHOP ON "EARTHQUAKE HAZARDS ALONG THE WASATCH FRONT, UTAH," JULY 14-18, 1986

More than 150 Federal, State, and local scientists, planners, engineers, architects, and emergency planners gathered in Salt Lake City, Utah, in July 1986 to review the progress and accomplishments of the 3-year joint USGS-Utah Geological and Mineral Survey assessment of the earthquake hazards of the Wasatch Front. The workshop was cosponsored by the USGS and Utah Geological and Mineral Survey, and by FEMA and the Utah Division of Comprehensive Emergency Management. Teams of specialists were asked to summarize the state-of-the-art understanding of the area's earthquake potential and its ground-shaking and ground-failure hazards. The teams also assessed the status of State and local implementation of the new research results.

The participants concluded that although great progress had been made in the evaluation of the earthquake hazards of the Wasatch Front area, State and local implementation of earthquake hazards reduction measures has been disappointing. The group developed a new research implementation agenda for Fiscal Years 1987 and 1988 to rapidly advance State and local participation in earthquake hazards reduction.

The workshop was highlighted by the presentation of awards to five individuals for their accomplishments in fostering implementation activities to reduce earthquake hazards in Utah. The award recipients were:

- Robert Madsen, Mayor of the City of Ogden;
- Genevieve Atwood, Utah State Geologist and Director, Utah Geological and Mineral Survey;
- Lorayne Tempest, Director, Utah Division of Comprehensive Emergency Management;
- Delbert Ward, Principal, Structural Facilities, Inc., and former Executive Director, Utah Seismic Safety Advisory Council (1977-1980);
- Lawrence Reaveley, Vice President, Reaveley Engineers and Associates.

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Utah Earthquake Hazards Workshop, July 14, 1988. Robert Alexander (center) of the USGS Rocky Mountain Mapping Center describes applications of a new digital geographic information system to Wasatch Front earthquake hazards assessments.

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NATIONAL SCIENCE FOUNDATION

In accord with the 5-year Plan for the National Earthquake Hazards Reduction Program, the National Science Foundation (NSF) is responsible for the following Program objectives:

- Seismic Design and Engineering Research. Fundamental and applied research, and the modernization of existing facilities;
- Preparedness Planning and Hazard Awareness. Societal response research (addressed by NSF in the earthquake systems integration element of its earthquake engineering research program); and
- Fundamental Seismological Studies. Implications of plate tectonics and the earthquake process.

EARTHQUAKE ENGINEERING RESEARCH

Siting and Geotechnical Systems

Siting and geotechnical systems research programs encompass specific engineering research investigations to measure and analyze strong ground motions, study tsunami generation and propagation to mitigate damage to coastal structures, conduct experimental and analytical studies of dynamic soil behavior and failure of geological structures, investigate the stability of ground structures like dams and abutments, and understand the process of subsurface ground damage to mitigate disruption of lifeline systems like utility lines and energy transmission systems. The research results from these individual but interdependent components of geotechnical systems contribute to improving present understanding of how the dynamic effects of earthquake ground damage occur and the engineering approaches that must be taken to mitigate earthquake hazards.

The September 19, 1985, magnitude 8.1 earthquake on the west coast of Mexico caused enormous loss of life and property in Mexico City, the effects of which are still being assessed. Because of unusual geological features, the earthquake waves propagated with much less attenuation over the 400 kilometers from the rupture site to Mexico City than is usual. The arrival waves then excited large vibrations of the ground at specific locations throughout the city as a result of the unique geology of the Mexico City basin. To better understand these and other features of this earthquake, especially those features which have implications for U.S. cities, eight awards were recently made in the area of siting and geotechnical systems specifically addressing the lessons to be learned from this earthquake.

Siting and geotechnical systems research focuses on the fundamental engineering issues related to earthquake ground shaking and estimates earthquake interactions on geologic structures including surface and subsurface soil and rock systems. The primary research areas are: strong ground motion research, tsunami engineering research, geotechnical systems and stability, and lifeline systems.

An annual planning meeting has been initiated centered around the current grantees of the Siting and Geotechnical Systems Program. The objectives are:

- To discuss the current challenges and roadblocks facing the research community, supported by the NSF Siting and Geotechnical Systems Program.
- To plan a strategy for tackling these problems.
- To note the progress and disseminate the accomplishments of recent past years.

Attendees consist of the current grantees and an equal number of experts from academe, national and government laboratories, and overseas, together with representatives from the funding agencies. The first meeting was held August 3-5, 1986, at the Illinois Institute of Technology. There was a strong emphasis on implementation of the goals of the 1977 Earthquake Hazards Reduction Act, resulting in seven specific recommendations and four action items.

Strong Ground Motion Research

The ability to measure and understand strong ground motion forms the basis for developing

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appropriate engineering design criteria for buildings, dams, and other major structures. Understanding the characteristics of ground motion produced by earthquakes is of fundamental importance in mitigating earthquake hazards. The strong ground motion research program is focused on resolving the following key issues:

- The engineering characteristics of near field, strong ground motions are not adequately understood. A quantitative determination of the principal and specific ground motion parameters that produce earthquake damage is needed to develop appropriate earthquake design methodologies.
- A verifiable data base on near field, strong ground motion needs to be developed with national and international earthquake data.
- Subsurface variations of strong ground motion are not adequately understood. This lack of knowledge on subsurface variations of ground motions presents a critical void in earthquake hazard estimations. A quantitative determination of this parameter is needed to develop design options for critical structures including subsurface structures, buried lifeline systems, and the design of deep foundations.

NSF has initiated cooperative research programs between U.S. institutions and countries which have a high potential to experience a major earthquake in the near future with the aim of establishing a global, strong motion data base. The cooperative programs include strong motion data activities with the People's Republic of China, Taiwan, Mexico, and India. This expansion of strong motion networks is now providing valuable field data on strong ground motions. Site-specific studies are being made to collect data on soil and geological parameters and relate them to corresponding strong motion data. This research will continue to upgrade our knowledge on site-specific strong motion response characteristics for large earthquakes.

The cooperative program in Taiwan involves an array of strong-motion accelerometers, known as SMART-1 (Strong Motion Array Taiwan, Number 1). It is sponsored by the Foundation through an award to the University of California at Berkeley, and is maintained by the Institute of Earth Sciences of the Academica Sinica of Taiwan. SMART-1 is in Lotung, a seismically active area; between January 1981 and June 1984, the array recorded 28 earthquakes. This data is being used in a project supported by the U.S. Electric Power Research Institute (EPRI). In cooperation with Taiwan Power, EPRI is conducting field experiments in Lotung to gather data for the development of a more realistic soil-structure interaction model. These models are used to simulate the effects of earthquakes on the foundation and buildings of nuclear power plants. Because of a lack of data accumulated during actual earthquakes, the U.S. Nuclear Regulatory Commission's Standard Review Plan 3.7.2. has specified a conservative design approach. This conservatism impacts the design requirements of the entire nuclear power plant. These experiments are being conducted on two containment models: a 1/4 scale model and a 1/12 scale model. They have been in progress since October, 1985, and in January, 1986, a 6.3 magnitude earthquake was recorded. Data from SMART-1 will be used in current and future EPRI studies to verify and refine seismic measurements made at the scaled model sites. The soft soil and high ground water tables at the Lotung site may prove especially valuable for studies of soil liquefaction and its role in the impact of earthquakes on nuclear power plants. A recent National Research Council study has identified field experiments, such as those in progress at Lotung, as the highest priority for future soil liquefaction research. Such experiments are now being planned by the University of California at Davis under an NSF grant, with the National Taiwan University and EPRI participating.

Geotechnical Systems and Stability

The earthquake responses of soil and geologic structures are nonlinear. The geologic patterns of layering and inhomogeneities in actual soil and geologic structures can be extremely complex and have a great effect on geotechnical engineering problems at a site. The behavior of a site can change with time because of changes due to construction, excavation, the stresses within the soil, fluctuations or permanent changes in the ground water regime, or other geological and geotechnical factors.

Geotechnical systems and stability research emphasize experimental and analytical studies

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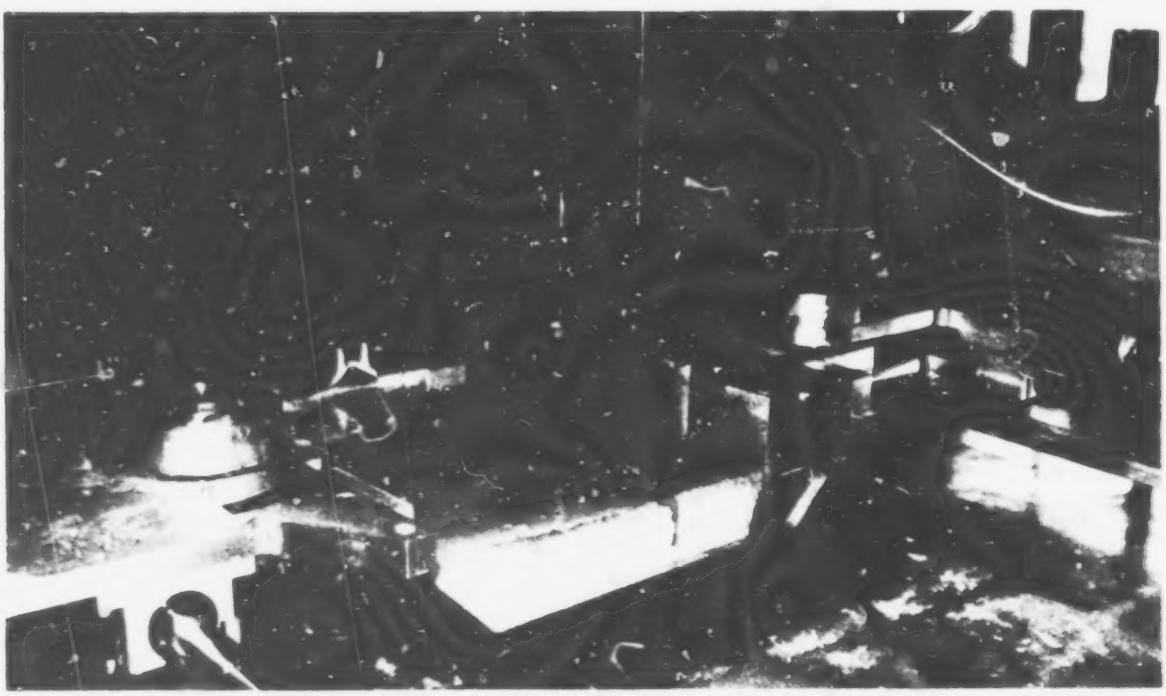
to upgrade the engineering understanding of earthquake ground failures such as liquefaction, subsidence and failure of foundation, slopes, and embankment structures. The goal is to provide appropriate geotechnical design criteria to mitigate earthquake damage of buildings, critical structures, and surface and subsurface excavations.

The research on geotechnical systems and stability is focused to resolve the following key issues:

- Available tools and methods to measure *in-situ* geotechnical parameters are inadequate and present a technical barrier to characterize a site and limit the applicability of appropriate design methodologies to increase earthquake ground stability.
- The engineering phenomenon of soil liquefaction is not fully understood. Geotechnical experts differ in their interpretation of the liquefaction process and on the certainty with which the liquefaction potential and safety of constructed structures can be assessed.

Of increasing concern is the safe isolation of toxic and nuclear wastes in large underground caverns. Such caverns are surrounded by jointed rock, and the permeability of the joints is of paramount importance to the safe containment of the toxic wastes. Of particular concern is the increase in the permeability of the joints as a result of earthquake induced strong ground shaking. Professors Dowding and Belytschko at Northwestern University have been investigating this phenomenon in an NSF supported study. The study involved the mathematical modeling of the rubbing between blocks and the resulting erosion of joint material; the numerical computation of the sliding of the blocks and the changes in joint permeability; and the development of an innovative test procedure to experimentally determine the effect of the erosion of material due to sliding. This apparatus now permits, for the first time experiments to be made on multiple duplicate specimens in real



Computerized Numerically Controlled Saw Table. This unique apparatus was developed by Professor Dowding as part of an NSF supported project at Northwestern University to investigate the integrity of large rock caverns, such as those now being used for the underground storage of hazardous wastes, when subjected to severe earthquake shaking. The joints that occur in rock are potential leakage paths for the stored material, and the rate of leakage can change as a result of earthquake motion due to changes in the geometry and thickness of the joint. To measure this leakage experimentally requires multiple rock specimens, all with the identical joint between the blocks. The picture shows the bandsaw cutting an accurate replica of a measured rock joint.

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rock using a specially designed, computer-controlled, band saw. The diamond band saw blade is able to replicate on any number of specimens of real rock the geometry of a measured rock joint, permitting multiple tests of identical specimens. This innovative apparatus thus permits experiments to be performed on real rock specimens that previously had to be performed on some substitute cast material. Such experiments have long been needed in many areas of rock mechanics research and testing.

Tsunami Engineering Research

Tsunamis are long, ocean surface waves generated by sudden displacements of large volumes of water. Most tsunamis are caused by strong ground motions from submarine earthquakes. Tsunamis pose a threat to coastal areas close to the epicenters of the earthquakes which generate them and can also threaten coastal areas thousands of kilometers away from their sources.

A single tsunami can cause death, injury, and destruction in a number of ways. The most obvious threat is from the inundation of low-lying coastal areas as the tsunami propagates slowly, implacably inland. A second threat stems from the force of waves breaking against obstacles in the path of the tsunami. A third, and in some cases the most serious threat, is posed by the flotation of objects varying from small pieces of debris to large ships and the resulting impact when they are driven against coastal structures.

The circum-Pacific tolls of death and destruction from major tsunamis are comparable to fatalities and damage by large earthquakes. These two catastrophic hazards are always causatively connected, but their effects are often geographically separable. Earthquake damage is generally confined to a zone adjacent to the rupture axis, whereas the tsunamis' influence is widespread and oceanwide.

NSF research emphasizes engineering research in tsunami hazard mitigation and is focused to resolve the following key technical issues:

- Tsunami hazard zoning is non-existent in the U.S. The development of verified, site-specific coastal response predictions to tsunamis is essential to reduce the potential devastation by future tsunamis in U.S. coastal areas.
- Available tsunami warning systems are not effective to provide a timely warning at the onset of a tsunami. The detection of tsunami generation is very critical for a viable tsunami alert system to mitigate tsunami hazards.

During the past two years, with support from the National Science Foundation, Professors W.G. Van Dorn and W.B. Thompson of the Scripps Institution of Oceanography, University of California at San Diego have been studying the responses of tide gauges to tsunami waves approaching from the open sea, using as data tide records of large past tsunamis. In contrast to the widely held opinion that the incoming waves maintain their identity as they are amplified in shallow water and rush up on the shore, the analysis of Van Dorn and Thompson suggests that the oscillations seen on tide records are simply a gross exacerbation of the normal background; that is, a system of standing waves on the continental shelf that is resonantly excited by any broadband low-frequency disturbance. The frequencies present (normal modes) are determined by the shelf dimensions; the propensity for resonant excitation by the abrupt depth change at the shelf margin; and the amplification limit by turbulent dissipation in shallow water.

During the past year, Van Dorn and Thompson have analyzed tsunami records from basins of four widely different sizes, and have been able to demonstrate that the same dissipation coefficient suffices to explain the rate of energy dissipation in all cases. This should make possible a closer estimate of the total tidal dissipation in the world's oceans, which in turn is responsible for slowing the Earth's spin rate. Thus this research which focussed on the prediction of tsunami waves' amplification as the waves approach the shore has yielded as a spinoff the contribution that tidal dissipation in the oceans makes to the slow down of the Earth's spin rate.

A close coordination is being maintained with Japanese tsunami researchers in order to

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transfer some of their modeling and tsunami data to develop a viable tsunami alert and prediction system that will be effective for use in the United States. A cooperative tsunami research activity was initiated between Texas A&M University and Tohoku University in Japan to verify a dispersive gravity model and identify the generation and propagation phases of a tsunami. This cooperative tsunami modeling activity would lead to the development of an effective tsunami alert system and rapid assessment of population and property damage zones near coastal areas in the United States which are prone to tsunami hazards.

Structural Systems

Structures are assemblages of components, subassemblies, and systems, each with defined performance standards that can be substantially modified by earthquake forces. During an earthquake these forces can have an effect on structural performance that ranges from no effect at all to complete loss of performance caused by collapse. The broad objective of the NSF earthquake engineering research program in structures is to develop improved methods for structural analysis and design, including data base, guidelines, engineering tools, etc. for design engineers, architects, planners, building officials, and code development organizations at the local, State and Federal levels, as well as the private sector.

The earthquake engineering research program for structures can be conceptualized as consisting of two basic elements. The first element is structural dynamic analysis and design research, and the second is dynamic structural experimentation research. These two elements are combined to develop specific research data and information.

The structural dynamic analysis and design research projects develop innovative concepts applicable to the 3-dimensional structural framework for structures and are usually expressed in the form of computer programs and methodologies for ultimate use in the design office. Of utmost importance to engineers and designers is the development of mathematical modeling and analyses describing the nonlinear behavior of the structure and its consitituent materials, components, subassemblies, and systems when subjected to actual earthquake motions or equivalent forces and loads.

The purpose of this analytical treatment is to allow evaluation and prediction of the dynamic behavior or response of a structure during an actual earthquake. Observed structural damage during an earthquake is an indication that the construction materials have been stressed beyond their linear range. Computer programs are developed that have the capability to simulate and predict nonlinear structure behavior.

Supercomputers are providing a new tool with exciting opportunities to advance dynamic structural analysis and design research capabilities by allowing more detailed mathematical modeling of the earthquake behavior of structures. Extensive use of this new tool is being made.

Dynamic structural experimentation is an essential element of the research program. The theoretical and methodological research concepts necessary for prediction of the behavior of structures are necessarily based on assumed conditions of material behavior and overall structural behavior. Application of these concepts to the actual design of a structure is not possible unless appropriate confidence in these assumptions exists. This is accomplished through dynamic structural experimentation where the predicted dynamic behavior is compared with that of actual prototype structures or models. This also allows validation of fabrication and field construction techniques, as well as the behavior of nonstructural components that are difficult to model analytically.

Experimental data describing the behavior of a structure can also be acquired by a controlled experiment on a full-scale structure or an instrumented structure that has been subjected to an earthquake. Using the mathematical method of system identification, the dynamic performance of the structure can be determined. This technique, along with computer program development, is used to assess the seismic vulnerability of existing structures as well as provide guidance in the design of new structures.

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Christa Eliot, Graduate Student in Civil Engineering at the University of Illinois, Urbana, collecting data during a cyclic-load test of a structural steel element. The experiments are being carried out to investigate flange buckling problems in girders subjected to earthquake forces in this National Science Foundation sponsored research project.

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An important part of dynamic structural experimentation research is the determination of methods of simulating earthquake loads and forces to structures. Advances are being made using controlled explosive techniques, explosive arrays, pseudodynamic methods, the shake-table simulation method, impulse excitation, and various methods of impedance testing. The results of this research will provide an economical and technically sound method of *in-situ*. full-scale and model structure excitation, thus allowing simulated performance to be observed.

Steel Structures Research

Steel is a relatively new structural material compared with wood and masonry. Because of the rapid increase in its many applications in modern construction, the emphasis of research in the dynamic behavior of steel components and systems has also increased dramatically.

During the September, 1985 Mexico Earthquake, a tall steel building of modern construction totally collapsed. To understand how a steel structure will respond to the excitations induced by earthquake ground motions, it is important to study the dynamic response of various steel member components, subassemblies, load-carrying systems, and entire structures. Many research projects have been undertaken, including a comprehensive large-scale experimental program conducted through US/Japan cooperation. Additional problems remain, however, and more research is required to develop innovative design concepts of steel frames with concentric or eccentric bracings for better economical and seismic performance, to investigate the energy absorption characteristics, to determine inelastic response due to multiple component loading, to investigate the effect of the 3-dimensional configuration of buildings, and to develop computer-aided design techniques, including computer graphics for seismically resistant steel structures.

Reinforced Concrete Structures Research

Reinforced concrete structures range from single-story buildings and warehouses to high-rise and apartment buildings. The type of construction for the different buildings varies between poured-in-place framework, tilt-up panels, and prefabricated, precasted or prestressed components, or both. Each type of construction has special design and construction characteristics of its connections and dynamic behavior when subjected to earthquake forces. Reinforced concrete structures have been used widely throughout the United States and many of them predate the adoption of building regulations for the design and construction of seismically resistant structures. However, from the experience of many past earthquakes, including the recent Mexico earthquake, reinforced concrete buildings are also very vulnerable to cyclic dynamic forces generated by earthquakes.

In order to construct new buildings of reinforced concrete, investigations are performed to determine the dynamic characteristics of the material in confined conditions, the cyclic behavior of components such as beams, columns, and floor systems, and the seismic behavior of subassemblies, frames, shear walls, and entire buildings. Analysis methods and computer programs which include the effects of the 3-dimensional features of the building when subjected to 3-directions of loading are developed.

Experimental investigations are conducted on the various units in order to establish material, component, and system behavior for simulated earthquake motions. The results of the analytical and experimental research are made available to professional designers, other researchers, and code-promulgating bodies at the local, State, and Federal levels as well as private code-writing groups.

A major program of large-scale testing of reinforced concrete buildings was recently completed and was conducted on the basis of U.S./Japan cooperation. The ultimate objective of this program was to improve design practice through joint research. Specific results have begun to appear via conference proceedings and reports of special technical sessions. An implementation report, targeted for practitioners to improve seismic safety design practices, is being prepared. Significant impact to the professional practice in seismic design is expected.

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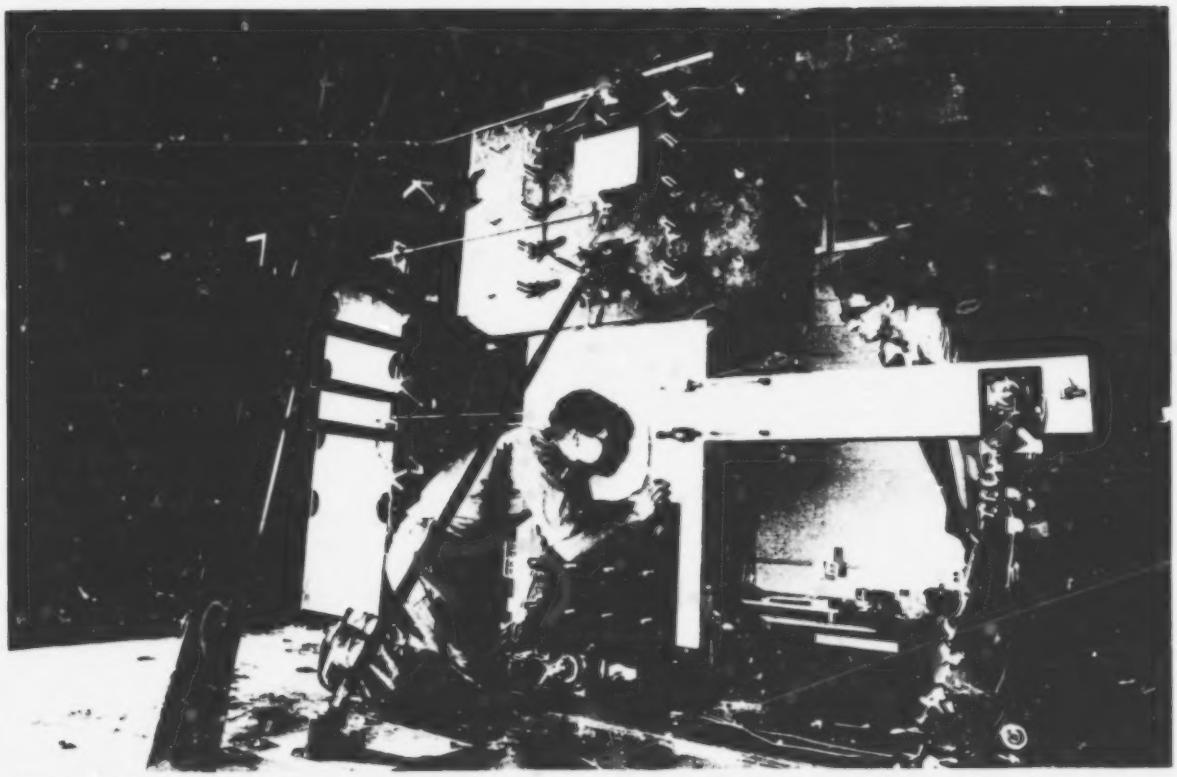

Graduate Students at the University of Illinois, Urbana, examining a reinforced concrete specimen after an earthquake simulation test sponsored by the National Science Foundation. The specimen has been designed to investigate displacement response of reinforced concrete structures.

Wood Structures

Wood is man's oldest structural material and only recently have steel, aluminum, concrete, and structural plastics assumed their present importance. The importance of wood as a structural material has not diminished, as is evident from a survey in the early 1970's showing that the tonnage of wood produced for industrial uses, including construction, was greater than that of steel and concrete combined.

A number of NSF research projects have focused on increasing knowledge concerning the behavior of wood structures during earthquakes. Research projects have established (1) a representative data base for material properties; (2) procedures for testing materials; (3) refined analytical procedures and computer programs; and (4) testing and analysis methods of simple bending components, intercomponent connections, and wood diaphragms. These efforts will raise the seismic-resistance threshold of wood structures, particularly those low-rise buildings existing in highly seismic regions of the country.

Wood has found its place in the construction of residential houses, low-rise apartment buildings, motels, and low-rise office buildings. Experience from recent earthquakes indicates that structural failures sustained by low-rise wooden structures result primarily from the inability of the structure to act as a unit or from inadequate lateral bracing provisions. Research activity in all types of applications of wood components in construction, such as seismic response of non-symmetric structures and effects of vertical ground motion on light-frame construction, is needed to design seismically resistant structures.

Computer Aided Engineering

Civil engineers are faced today with new chal-

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lenges in applying rapidly advanced technology to meet the expanded society's needs in the design, planning, construction, operation and management of public and private works such as bridges, buildings, dams, and water systems. One critical area of problems which can be effectively dealt with is the safety design of such structures. Research in the development of computer aided engineering methodologies and tools for seismic analysis and design is being initiated, and applications of new computers and computer technologies in solving earthquake problems are encouraged.

Expert Systems Research

While much progress has been made on theorectical as well as experimental investigations in earthquake engineering, there exists many problems where the solutions must rely on the experience and intuition of a few selected experts. The development of "expert systems" will enable experts to transmit their valuable and unique knowledge to improve the professional practice, assist new engineers to acquire experience at a faster pace and more efficiently, and provide individual experts with a collective decision-making model on a consultative basis. It is expected that such research activities will not only improve the practice in earthquake engineering but also stimulate interdisciplinary research efforts.

"Expert Systems" are generally implemented through computer programs which are developed using a collection of facts, rules and experts' knowledge to solve problems in specialized subject areas. The study of expert systems is a branch of the subject area of artificial intelligence. To date, more than 80 expert systems have been or are being developed in various fields such as medical diagnosis, oil-well log interpretation, and computer system configuration. At the present, research is being supported by the NSF to develop expert systems for earthquake engineering applications. These computer programs consist of the following three parts: inference machine, knowledge base, and memory. The inference machine consists of several reasoning methods and the solution is obtained on the basis of available data in the memory according to rules in the knowledge base. In the knowledge base, there are the knowledge expressed in terms of rules for damage assessment, and metarules with which the rule group and the suitable inference method may be chosen. Available information including inspection data, details of specific buildings and resulting conclusions from previous case studies is stored in the memory. This type of investigation was initiated at Purdue University and has rapidly spread to other research institutions.

Safety and Damage Assessment Research

Structures and facilities in seismic regions are expected to sustain and tolerate certain degrees of damage during earthquakes of differing intensities. In many instances the ability to predict the damageability of a structure is important when decisions are to be made on whether to retrofit an existing building that is exposed to seismic hazards, and when an optimum choice is to be made among various options available to upgrade the seismic resistance of a critical industrial facility.

In general, the assessment of structural safety or damage must be based on a thorough understanding of the seismic behavior of the type of structure under consideration. It is, therefore, important to acquire a comprehensive damage data base by analytical, experimental, and empirical means. Research projects have been initiated toward this goal, and research to develop a rational method to integrate the experts' judgment with the results of engineering analysis is also being conducted. Eventually, a computer methodology for reliable safety and damage assessment will be developed that synthesizes the engineering information and the subjective opinions.

Offshore Structures Research

Large offshore structures, such as the 900-foot Honda drilling platform off the coast of Santa Barbara, California, represent large capital investments and can pose potential environmental hazards. Such structures are subjected to the combined forces produced by waves, winds, storms, and earthquakes. Further, the complicated dynamic behavior and stability of these structures are influenced by the interaction between the foundation soil, the platform structure, and the fluid. For many

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years, U.S. oil companies and their design firms have closely followed state-of-the-art knowledge and research, and have used advanced methods of earthquake analysis and design for offshore structures located in seismic regions of the world.

The damage to an offshore structure can be both costly and catastrophic. For example, in January 1982, the huge steel oil rig Ocean Ranger — a 37-story high and two city block square structure which was considered unsinkable — capsized in the North Sea. The $125 million structure, which was designed to simultaneously withstand 100-knot winds, 110-ft. waves and a 4-knot surface current, sank in the hostile ocean along with its 84-member crew.

Research is conducted to study the effects of currents and water on the submerged tubular column members, and the effects of water depth and joint flexibility on the overall dynamic response of the platform structure. Methodologies to evaluate the damage state of the offshore platform and structures, and their safety design against combined action of extreme forces, are being initiated.

Architectural and Mechanical Systems

Architectural and mechanical systems generally comprise that portion of a structure generally not taken directly into account when evaluating the strength of a structure or its resistance to applied forces, as well as other items such as computers and building contents, mechanical equipment, and electrical distribution equipment.

Architectural and mechanical systems are important to earthquake hazard mitigation. Experience gained from the 1964 Alaska Earthquake, the 1971 San Fernando Earthquake, and other earthquakes, has shown that damage to nonstructural items can result in major economic loss, make structures functionally useless, and cause serious injuries and economic losses.

Architectural systems are generally defined as exterior systems and interior systems, which may also need retrofitting and upgrading. Examples of exterior systems are cladding and glass panels. Examples of interior systems are ceiling and floor systems, and interior partitions. Mechanical systems include interior equipment, exterior equipment, and base isolation. Examples of interior equipment are HVAC systems, computer systems, and electrical distribution equipment. Examples of exterior equipment are transformers and sub-stations.

Nonstructural Components Research

Nonstructural components are those assemblages and equipment that are normally not accounted for in determining the strength and response of the primary structure to an earthquake. Two examples of nonstructural components are suspended ceiling systems and architectural cladding. Failed nonstructural components in a structure have in many instances been too costly to repair or replace and, thus, demolition of the entire building has been required even though the principal structural framework was only slightly damaged. In addition, the greatest loss of life in a building results from dismemberment of the nonstructural components. Research projects have been studying many varied methods to overcome or reduce the damage resulting from the dislocation of nonstructural components.

Equipment such as heating, ventilating and air-conditioning systems, electrical equipment, pumps, cabinets, and process equipment are extremely important to the proper functioning of a structure. Failure of equipment during an earthquake can make an entire structure nonfunctional, and many times this failure can be prevented. Research is conducted, therefore, on the response of different types of equipment during an earthquake, as well as the interaction of this equipment with the main load-carrying frame. The final uses of the results of the research are by the designer, the structure owner, the building officials, and the code authorities.

Building configuration studies that relate symmetrical and nonsymmetrical aspects of floor plans to potential building damage are continuing. Other architectural features of the building, which include ceiling systems and

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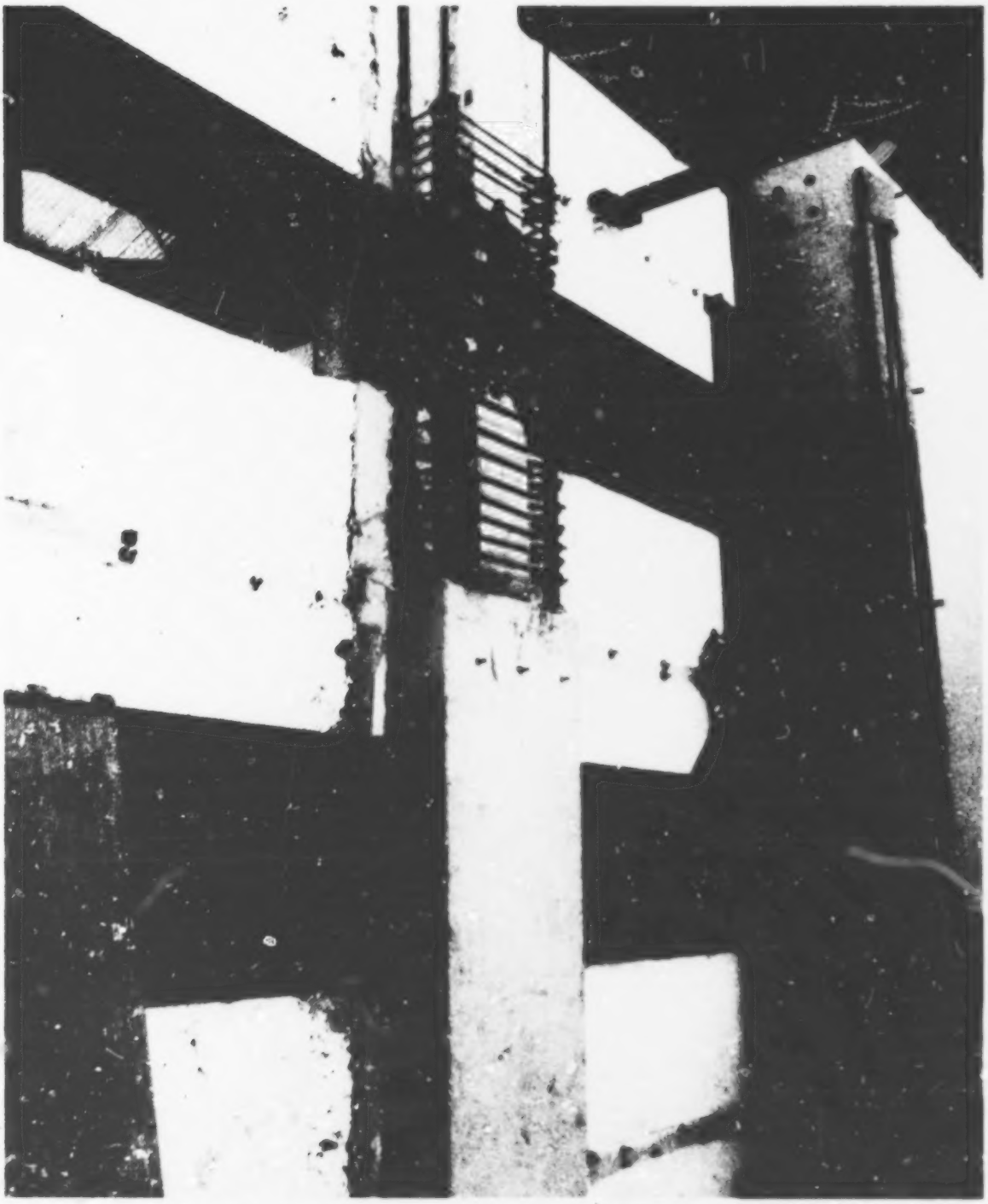

This National Science Foundation sponsored research project is investigating the repair and retrofit of structures damaged by earthquakes. This shows a building column in the process of being repaired using techniques developed in the research studies. The project is being conducted by the University of Texas at Austin and H. J. Degenkolb Associates, Inc. of San Francisco.

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partition systems, could contribute significantly to damage, loss of life, injury, and time required to restore an earthquake-damaged building to normal service functions.

Research on Existing Structures

For existing structures and buildings, the most important application of reserach results is the determination of their seismic resistance when they were constructed prior to the adcption of modern seismic building regulations and codes. When an existing structure is determined to have inadequate strength and behavior to accommodate seismic forces, two options exist: (1) the structure can be demolished and new one constructed, or (2) the existing structure can be strengthened to upgrade its serviceability to higher standards.

The need for factual data and design information on the repair, strengthening, and retrofit of existing buildings is paramount to mitigate earthquake hazards. Economic and effective methods for strengthening exisiting reinforced concrete, unreinforced masonry, and steel structures are needed in order to upgrade these to an acceptable safe standard. Additionally, analytical techniques and computer programs are needed for the prediction of performance of existing structures under seismic loads. Many of these data and techniques also may be applied to the repair of structures that suffer minor damage during an earthquake; they can thus be salvaged at a minimum cost.

Many bridge structures in this country have deteriorated to a point where their strength and seismic resistance are unknown. There is an urgent need for data and development of methodology and design information to allow these bridge structures to be stengthened, repaired, and retrofitted at minimum cost.

Research is required in several areas in order to address the problem of existing structures and buildings. These include technical and engineering methodologies and requirements; public policy, legal, and financial strategies: special considerations of historic buildings; and technology and knowledge transfer mechanisms.

Base Isolation and Energy Absorption Systems

The concept of isolating structures from the effects of an earthquake is receiving increasing attention from researchers. By isolating a structure from the effects of an earthquake, destructive forces are reduced in structural members, thus reducing material costs and construction costs. Not only are the structural forces reduced, but the forces imparted to equipment and nonstructural elements are also limited, thus decreasing the potential for their damage and the resulting loss of function. Base isolation systems reduce the lateral earthquake loads on the structure and hence will allow structures to resist minor earthquakes without damage; resist moderate earthquakes without structural damage, but with some nonstructural damage; and resist major earthquakes without collapse, but with some structural as well as nonstructural damage.

Various base isolation schemes and configurations are being investigated by researchers. Other types of controls and energy absorption devices being studied include active control of a structure during an earthquake (i.e., motion is imparted to the structure to cancel out that imparted by the earthquake). Also, viscous and friction elements are being considered as passive control devices for inclusion in the structural system or structural elements to dissipate the energy from an earthquake.

Both analytical research and experimental research on base isolation systems show that it is possible to predict structural response of the systems as well as reduce the earthquake motions transmitted to the structure and its contents. Additional research is needed and required in analytical response analysis, the effects of aging and environment on material properties and response, and full-scale experimentation. Accompanying these, it is necessary to develop methodologies for the application of base isolation to general structures. These include the development of design rules and guidelines and research for code development.

Masonry Structures

Masonry is one of the oldest construction materials used and one of the least researched.

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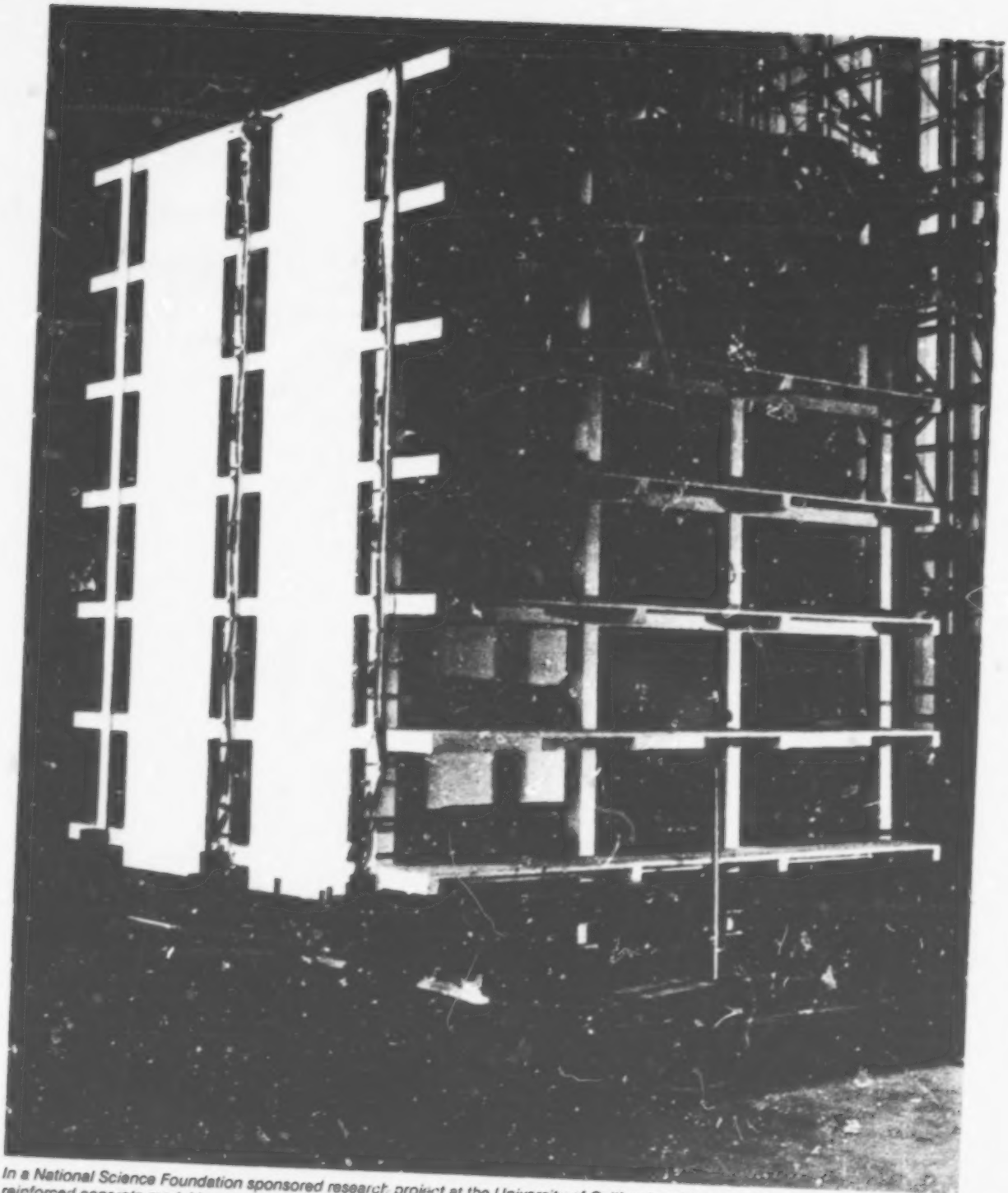

In a National Science Foundation sponsored research project at the University of California at Berkeley a six-story, 1/5-scale, reinforced concrete model is mounted on seismic isolators on a shake table used for simulating earthquakes. The model had been tested previously without base isolation and had been very badly damaged. The model was partially repaired and isolated. The experiments show that base isolation can reduce the retrofit and rehabilitation requirements of earthquake damaged structures.

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Masonry construction, because of its widespread use in structures located in seismic regions — particularly in underdeveloped areas — has contributed to many of the fatalities and injuries suffered during destructive earthquakes. For example during the 1976 Tangshan earthquake in China, most of the destruction that caused a death toll of (officially) 230,000 people was associated with buildings of unreinforced, unengineered masonry construction.

There is a worldwide interest in masonry construction in moderate to high seismic zones because of its apparent features of economy, fire safety, architectural flexibility and ease of construction. Current knowledge of the dynamic behavior of masonry structures is insufficient for proper aseismic designs, despite its long history of use. The dynamic behavior is complicated because of the wide variation in material units; types of construction; workmanship; and more importantly, the lack of adequate design guidelines and specifications for aseismic construction. Research efforts are being expanded to develop improved mathematical models using experimental data for masonry structures using system identification methods. Laboratory experiments are conducted on typical masonry piers and walls, with and without reinforcement, to determine their lateral load resistance. Methods are also being developed for retrofitting or strengthening the earthquake-resistant capability of existing hazardous masonry buildings. Other projects are underway to investigate the dynamic behavior of floor and roof connections, to establish techniques to repair unreinforced masonry walls with epoxy or grout-bonded reinforcement, and to develop nondestructive techniques for the evaluation of material properties for existing walls.

Experimental Facilities

Various experiments are performed on materials, subassemblies, components, frameworks, walls, floor systems, and 2- and 3-dimensional structures in order to develop data for mathematical modeling, verification of analysis and design principles, and detailed construction features.

In order to perform the required experiments, many different types of earthquake simulators and pseudodynamic methods have been developed. However, the actual performance of a structure such as a building, bridge, storage tank, or dam during an earthquake is the ultimate proof of the validity of the analysis methods and construction features. But all types of structures cannot be evaluated in this manner, since this investigation technique requires a careful study to determine which structure should be instrumented and the clairvoyance to select the next possible earthquake event. Because it is a difficult task to determine when and where the next earthquake will occur, other methods of simulating an earthquake have been developed. These simulation methods are as varied as the structures to be studied and, therefore, are suitable for different purposes. The techniques are: large and small earthquake simulators (shake tables), reaction walls, high explosives, contained explosives and full-scale experiments involving externally applying forces, and instrumenting buildings that are expected to be shaken during a strong-motion earthquake.

Currently, some of the larger shake tables include a 20 x 20-foot shake table at the University of California, Berkeley; a 12 x 12-foot table at the State University of New York at Buffalo; and a 10 x 10-foot table at the University of Illinois. These simulation facilities have various mechanisms to load the specimen and each has limited capacities of specimen weight and degrees of freedom of motions that can be applied to the shake table. During the past several years, an upgrading of these academic facilities has taken place and they are becoming operational as quickly as possible. Besides the shake tables noted above, other types of experimental facilities are in use at different university campuses throughout the country. Most of these are small and medium-sized pseudodynamic facilities operated by faculty and graduate students.

Building Codes Research

Although all of the earthquake research activities eventually lead to design guidelines and code development, some projects form the basis for code provisions or revisions immediately upon completion. Projects of this type include:

- Development of nondestructive techniques to evaluate the mechanical properties of

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masonry construction which enables a designer to determine the strength characteristics of masonry walls to evaluate seismic behavior.

- Establishment of limits of thickness for which fire affects the strength of epoxy-repaired, reinforced concrete structures. These data were the basis for design guidelines and a city ordinance.
- Incorporation of data derived from research experiments of out-of-plane seismic behavior of masonry walls of clay bricks, concrete block, and structural clay products, in the Los Angeles city ordinance that pertains to the upgrading of unreinforced masonry buildings.

Lifeline Systems

Lifeline systems such as natural gas and oil pipelines, water sewage lines, and subsurface tunnels generally experience damage during strong earthquakes, thereby threatening lives and causing severe disruption to communities. Each type of lifeline system encompasses several different structural and mechanical components and covers land areas that vary significantly in soil characteristics and geologic structure. Lifeline systems research emphasizes engineering investigations to understand the failure process of lifelines, and develops economically feasible engineering safeguards to maintain earthquake serviceability for essential services that are critical for the sustained survival of a community affected by earthquakes. NSF's Earthquake Hazard Mitigation Program is the major sponsor of research on lifeline earthquake engineering in the United States.

Subsurface Lifelines Research

Subsurface lifeline systems are primary lifeline systems which include buried pipeline systems, passage ways, and tunnels used to transport energy, natural gas, water supply, and sewage supplies. Damage and destruction to such subsurface supply systems have short-and long-term impacts on the survival of a community affected by earthquakes. The short-term impacts include the failure of critical energy and utility services in an earthquake emergency, including the outbreak of fire and explosions due to the sudden damage and rupture of pipeline systems. The long-term impacts include major economic disruptions to the community affected by earthquakes.

Preventing subsurface lifeline failures by earthquakes is critical to the continued survival of a community during earthquakes. The subsurface lifeline systems research is focused to resolve the following critical issue:

> *Verified design guidelines to mitigate the damage to subsurface lifeline systems including oil, water, sewage, and gas transportation systems are not currently available. The lack of adequate field data and appropriate methods to assess earthquake response of subsurface lifeline systems is a severe restraint to develop economic design guidelines to protect subsurface lifeline systems during major earthquakes.*

The systems aspect of lifelines is emphasized in subsurface lifelines research. An approach to develop earthquake resistant design of subsurface lifeline systems must consider all aspects of load variations within and around the lifeline systems including external earth pressure and internal pressure in pipeline systems, soil and settlement conditions, and the effect of earthquake loading on these loads.

Research results have shown that in spite of the wide range of pipe and joint materials, and soil and backfill conditions, a series of representative pipeline systems can be modeled with reasonable accuracy for analyzing the earthquake response. Probabilistic models and associated computer programs were developed to derive reliability estimates for failure of the system and to identify the weakest link in the system. Finite element analysis methods of underground pipeline systems were developed, taking into account the nonlinear soil friction and transverse bearing response at the pipeline-soil boundary.

Earthquake emergency response of pipeline systems was studied using a case study area in San Francisco. The work has drawn on the multidisciplinary assistance of the San Francisco Fire Department, Water Department, and Utilities Engineering Bureau, as well as the Pacific Gas & Electric Company and panels of internationally known experts. The research has provided

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modeling procedures that can be used by municipalities to improve their pipeline systems and choose emergency measures tailored to their specific needs.

A U.S.-Japan workshop on subsurface lifeline systems was organized and held in Tsukuba Science City in December, 1985. The workshop provided an opportunity for U.S. earthquake researchers to gain a firsthand familiarity with the Japanese research developments in earthquake resistant design of subsurface lifeline systems since 1972 using criteria which have been established through extensive experience and research in several aspects of earthquake failure of lifeline systems. Based on the discussions at the meeting, U.S researchers have established two high priority areas of research projects to mitigate potential earthquake damage to subsurface lifeline systems. These are defining ground motions and conducting appropriate analytical and experimental investigations of continuous and segmented buried pipelines in weak soils including liquefied soils, and developing models and conducting prototype testing of soil restraints on buried pipelines for large earthquake displacements.

Above Surface Lifelines Research

The above surface lifelines systems are those systems or facilities that are supported on the ground or by elevated supports or supporting frames, or in a structure such as a building or tower. In these cases the dynamic interactive effects between the lifeline systems and the supporting soil foundation, though important, are of a lesser extent when compared with subsurface lifelines. In many situations, the size of the system, geometry of its layout, and system redundancy all play a prominent role in its behavior and safety design against seimsic load.

These systems, unlike buildings, cover large areas, sometimes extending several miles. They are generally parts of the networks and are composed of parallel and intersecting segments and linear paths that traverse great distances. Each type of lifeline system encompasses several different structural and mechanical components and covers land areas that vary significantly in soil characteristics and geologic structure. Understanding how lifeline systems are structured and how they are interrelated with other construction segments and ground conditions is important for design.

Research projects are being initiated for development of system/network analysis approaches for lifeline risk and reliability analysis, taking into account system redundancy and cost optimization. For a long-term viewpoint, it is important also to develop electronic control and monitoring systems for network lifelines using state-of-the-art sensors (e.g., multiple fiber-optic sensors) and microprocessor based computer control systems. The sensor system might consist of distortion-sensitive fiber cables and cable-induced pressure or thermal changes at key locations along lifeline (i.e., gas, water, etc.) systems. The data acquired would be processed on site to determine automatic shut-off or other mitigating actions as required. Naturally, field and laboratory experiments are necessary to verify the theories and design concepts, the practical designs for equipment supports, connections, and bracings, and other engineering measures for improved seismic safety.

Earthquake Systems Integration

Earthquake mitigation and preparedness efforts must focus on numerous systems including geotechnical, structural, mechanical and institutional systems. The Earthquake Systems Integration element is designed to integrate knowledge on such systems in order to reduce the vulnerability to earthquake hazards in the United States. It is also designed to link knowledge-producing and knowledge-using systems in the earthquake hazards mitigation field. Research and related activities such as information dissemination are supported to improve the basis for actions taken by practitioners and policy makers to mitigate, prepare for, and recover from earthquakes. Researchers from such disciplines as engineering, architecture, the social sciences, and planning are included in this part of the program.

Another concern of the element is to support research which provides needed insight into the social and institutional context in which hazards

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reduction must take place and thereby complement other research that is being done under the national program. For example, studies on the institutional and planning aspects of mitigation and preparedness that are supported by Earthquake Systems integration complement engineering research on structural mitigation and earth science research on prediction by linking important human factors with technological innovation and discoveries.

Four areas received major attention under this element in Fiscal Year 1986: (1) mitigation planning research; (2) preparedness planning research; (3) impacts, recovery, and reconstruction research; and (4) technology delivery. Recent earthquakes, such as those in Chile and Mexico, continue to provide evidence of the importance of these topics. Technology delivery involves such activities as the dissemination of information on hazards through workshops, conferences, information clearinghouses, and other means. Dissemination activities will be discussed in a latter section of this report.

Mitigation Planning Research

The work supported by NSF on mitigation planning is intended to further the understanding of the nature of particular mitigation programs in the United States and to account for variation in their effectiveness. Special attention is given to the technical and institutional barriers to the adoption and full implementation of mitigation measures in vulnerable regions of the United States.

Henry Lambright of Syracuse University recently completed an NSF-funded study on the role played by States in earthquake hazard reduction. A major focus of the research was the Southern California Earthquake Preparedness Project (SCEPP), an intergovernmental hazards reduction effort, which includes participation from the private sector. The final report of this study offers important insight into the pattern of local and State government involvement in hazard reduction activities and the conditions that lead to the development and evolution of such institutions as SCEPP.

The 1964 Alaska earthquake had major impact on communities throughout the State and for a time drew the attention of its inhabitants to their vulnerability to earthquake hazards. A recently completed study conducted by Lidia Selkregg and her associates at the University of Alaska, and Jane Preuss at Urban Regional Research, found that in spite of this experience serious obstacles remain in implementing seismic safety measures in Alaska. The NSF-sponsored study focused on the role of scientific information, public administration, and planning efforts to mitigate the effects of earthquakes based on the experience of the 1964 earthquake. The study found that the critical obstacles to the implementation of seismic-reduction measures in Alaska include insufficient scientific information, inadequate planning models, and lack of commitment. The final report concludes with a set of recommendations which are tied to a comprehensive planning and administrative model for hazards mitigation.

Robert Yin and associates at the Cosmos Corporation undertook a major study on the utilization of research results by practitioners and decision makers. The final report analyzes why and how innovations derived from engineering and social science hazard research are used by practitioners and decision makers and the policy implications of the findings. The nine case studies completed by the project include an analysis of the utilization process in connection with research on unreinforced masonry buildings and case studies tracing the utilization process in connection with research on hazard insurance and earthquake prediction. A follow-up project is under way which is assessing the role of professional associations and organizations in facilitating the application of research results.

Japan has launched major programs to mitigate and prepare for future earthquakes. Such efforts extend to both the public and private sectors in that country. Currently, we know more about government mitigation efforts in Japan than about what is transpiring there in the private sector. Robert Reitherman of the Reitherman Company has undertaken a study which focuses on earthquake mitigation and preparedness programs in Japan's private sector and their possible applicability to the U.S. The research is being conducted in both Japan and the U.S., and special attention is being given to identifying techniques and

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approaches used in Japan that could be adopted by companies in the U.S. Three reports on the resuts of this project will soon be released.

Preparedness Planning Research

NSF supports research on preparations for coping with both the primary and secondary effects of earthquakes, including ground shaking, tsunamis, and fires. Support is also provided for research on preparedness strategies for such critical systems as medical care and fire protection systems. Additionally, the research community has been encouraged to investigate the opportunities and dilemmas posed by the emerging technology of earthquake prediction.

Richard Olson of Arizona State University is completing research on the effects of a prediction made in 1980 of a damaging earthquake for Lima, Peru. The study is assessing the effects of the prediction on Peru's hazard mitigation and preparedness actions, its economic system and the public. The project suggests that this experience has important implications for the U.S. as well as other urbanized Western societies.

At the University of Southern California, William Petak and his associates are completing a project on earthquake hazards and the physically disabled. The researchers have developed a taxonomy of disabilities and how types of damage affect people with various kinds of physical limitations. Another aspect of the study is the evaluation of the plans and preparations for earthquakes of a sample of nursing homes and intermediate care facilities, institutions which typically serve large numbers of persons with physical limitations. Data have also been collected on the actions taken by the physically disabled during earthquake emergencies and the incidence of physical injury. Policy options for increasing the safety of the disabled are now being developed by the investigators.

Charles Scawthorn of Dames & Moore has been analyzing the fire potential following earthquakes in urban regions of the U.S. and the level of preparedness which currently exists to combat the problem. His study shows that inadequate attention has generally been given to this problem, even though some of the largest urban fires have been post-earthquake fires He has developed an analytical model which should prove useful in increasing preparedness for post-earthquake fires. He is presently including data from the 1985 Mexico earthquake in his analysis.

Impacts Research

NSF continues to support research on the impacts of actual earthquakes and patterns of recovery. Such studies are important because they can identify the problems that mitigation and preparedness measures should address. NSF has also supported research on earthquakes that occur overseas when there are lessons that can be learned which are relevant to hazard reduction and preparedness issues in the U.S. For example, research has been encouraged on the impacts of the March 3, 1985, Chile earthquake and September 19, 1985 Mexico earthquake because these two countries share some similar construction pactices and building types with the U.S.

Bruce Baird at Safety Sciences, Inc. is completing a project on the experience of hospitals and nursing homes in recent earthquakes, including the 1983 Coalinga disaster. Preliminary results suggest that staff training is only one component of overall institutional system safety which also includes such factors as building design and layout, security of contents, and evacuation planning. When the analyisis is completed, guidelines will be developed for internal hospital and nursing home disaster planning, health care staff emergency training, and emergency medical service and triage protocol design.

Samuel Aroni and Michael Durkin at UCLA recently launched an epidemiological investigation of recent U.S. earthquakes, including the Coalinga earthquake. This NSF-sponsored project was later expanded to include research on the Chilean earthquake. In both the U.S. and Chile, the research is aimed at identifying possible associations between specific types of injuries and specific physical settings and occupant actions When completed, the project is expected to significantly increase the data base on human injury in earthquakes and provide the basis for the formulation of

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design, planning, and occupant response guidelines for various types of buildings.

The Mexico earthquake has provided the opportunity for U.S. investigators to learn vital lessons regarding the impacts of such events. Among the NSF-sponsored investigators who are working cooperatively with Mexican counterparts are Frederick Krimgold and Antoine Hobeika of the Virginia Polytechnic Institute and Russell Dynes and his colleagues at the University of Delaware's Disaster Research Center. Krimgold and Hobeika are investigating search and rescue problems, and transportation problems, respectively, while Dynes and his associates are studying the organizational response to the earthquake.

FUNDAMENTAL STUDIES

The National Science Foundation supports research on all aspects of the fundamental earthquake process. Greater understanding of the tectonic conditions of earthquake occurrence will directly lead to improved estimates of where and when earthquakes are likely to occur as well as estimates of likely earthquake size and the effects they might generate. Thus, research on the basic conditions of earthquake occurrence will provide a framework for more applied programs of earthquake prediction and hazard evaluation.

There is an obvious need to understand the broad regional process by which stress accumulates before major earthquakes. The process is clearly mechanical but nonetheless complex and most difficult to detect. Some hints of the process are revealed by observations of seismicity and ground deformation, but until now these observations have proven almost contradictory and most difficult to interpret. Even so, a fundamental understanding of the geometry of tectonic stress before major shocks must be vigorously pursued because such understanding is a key to earthquake prediction and hazard evaluation.

A major effort is also needed toward understanding why large earthquakes sometimes occur away from plate boundaries within plate interiors. While such earthquakes are not as large as the great plate boundary earthquakes, these interior or intraplate earthquakes often have an importance out of proportion to their size or tectonic significance. That is, their importance derives, among other reasons, from their locations which are often near population centers and the sites of critical facilities, e.g., central and eastern United States. In such circumstances a moderately large earthquake might have the same social and economic consequences as a great earthquake in a more remote area. For these reasons the spatial distribution of these events within the interiors of plates has long been a major interest of seismologists and other earth scientists.

A key element toward understanding both stress accumulation and intraplate earthquakes concerns the nature of faults and other buried structures, particularly those in the lower crust and their interaction with the upper mantle. Recent NSF initiatives, including COCORP deep crustal studies and tomographic inversion of seismic travel-time data, have provided important insights into the tectonics of the lower crust and upper mantle. Near those fault segments where large earthquakes are considered likely, this detailed understanding of deeper structures may provide a real step forward in recognizing and interpreting small signs of stress accumulation. Many indications of seismicity changes or ground deformation have been reported before earthquakes but these indicators have not been consistent. An accurate map of deeper structures near a location where a large shock is expected should provide a reasonable basis for interpretation of stress indicators. In this way some estimates of timing might be possible.

Studies of Strong Ground Motion

In the field of strong motion seismology, the National Science Foundation has supported research which will eventually lead to an improved ability to predict damaging ground motions and to a greater understanding of physical properties of the earth. A basic problem has been to describe the ground motions which pose a threat to a structure. While sometimes the peak amplitude of ground motion is taken to represent the level of shaking, more demanding engineering re-

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quirements require information from a spectrum. The mix of frequencies in the strong shaking during earthquakes, and how strong the shaking is at each frequency, is described by a Fourier spectrum. The usual way to describe this spectrum for engineering applications is from complicated formulas which fit existing data but are determined without sufficient physical understanding. Large uncertainties result.

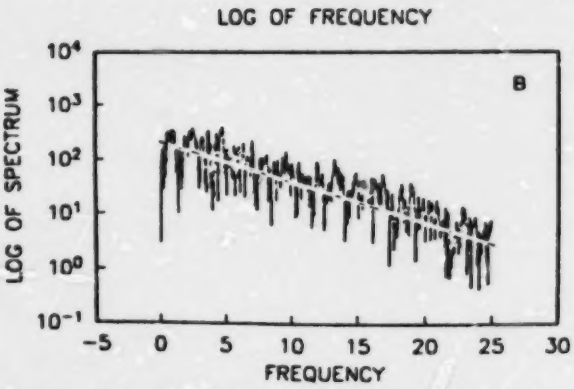
John Anderson and Jim Brune of the University of California, San Diego, have discovered that at high frequencies, the spectrum has a very simple underlying structure. When plotted, the overall trend can be described as a straight line, with some fine structure superimposed. The slope of this line is labeled by a parameter "kappa." The "kappa" value measured for an earthquake at the El Centro station, which is on thick sediments, was much larger than for that measured at the hard rock station at Pinyon Flat. For both stations, the values increased as the distance to the earthquake increased.

To apply this to earthquake hazard reductions, the first thing to note is that kappa for close earthquakes describes a characteristic of the station that can be measured using small earthquakes to help predict the shape of the spectrum in large earthquakes. Second, it is now becoming clear that differences in this parameter contribute in a significant way to differences in strong motions of differing regions of the Earth, such as between the eastern and western United States. Thus eventually, with more research, this will improve the ability to use accelerograms recorded in one place for hazard reduction in another.

The same parameter is also related to how earthquake waves lose energy as they travel through the Earth. The way kappa increases with distance tells us that near the surface, seismic waves lose energy very fast (faster at El Centro than at Pinyon Flat), but at depths where the earthquakes occur, the waves lost almost no energy. Below the earthquakes, the energy losses increase again.

Occurrence Parameters of Large Shocks

Earthquake investigators now realize that large earthquakes of the same magnitude act-



Log plot of strong shaking amplitude against frequency. Notice the overall straight line trend.

ually differ substantially in many parameters which are related to their occurrence. It seems probable that these major differences are generated by specific tectonic conditions which virtually control the entire earthquake process. Thus, significant insights into the earthquake process may actually be found by investigating these differences among larger shocks.

Fumiko Tajima of the University of Texas and Hiroo Kanamori of the California Institute of Technology have recently studied global variations in the patterns of aftershock areas for large earthquakes. Their results show significant variations among subduction zones which are most probably caused by the nature of the subduction coupling. Thus, the expansion of aftershock areas with time is relatively small in the subduction zones of Alaska, the Aleutians, Mexico, and parts of the Kuriles and South America. These subduction zones are interpreted to be characterized by moderate to strong interplate coupling. In contrast, the extent of aftershock expansion is greater for events within the subduction zones of northeast Japan and the western and south Pacific where interplate coupling is inferred to be weak. These results are consistent with an asperity model in which a source area is represented by a distribution of strong spots (asperities) and weaker zones. The rupture during the main shock mostly involves asperities. After the main rupture is completed, the stress change caused by the main shock gradually propagates outward into the surrounding weaker zones. This stress propagation manifests itself as expansion of aftershock activity. If relatively small asperities are densely

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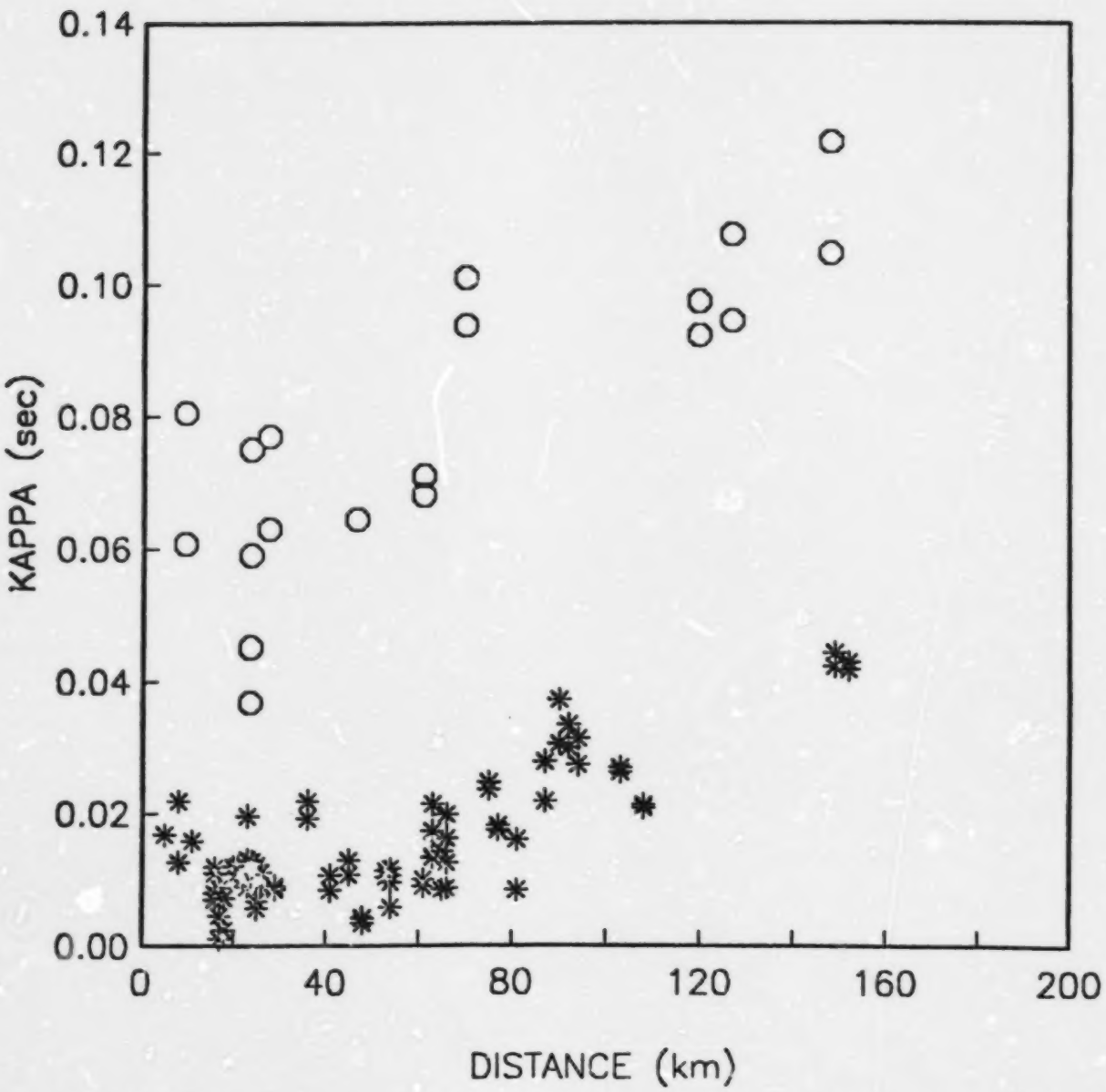

Values of 'kappa' measured at two different stations for different earthquakes. Values for the El Centro Station in Imperial Valley are designated by hexagons; values for the Pinyon Flat Station are represented by asterisks. Notice that the values increase with distance for each station.

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distributed and separated by small weaker zones, no extensive aftershock expansion is expected. The Mexican subduction zone is a typical example of this type. On the other hand, if smaller asperities are sparsely distributed, large aftershock area expansion is to be expected (e.g., Northeastern Japan, Philippines, New Hebrides, and Tonga-Kermadec). Thus, the aftershock area expansion pattern is strongly indicative of mechanical conditions of source rupture.

Tectonic Basis for Earthquakes

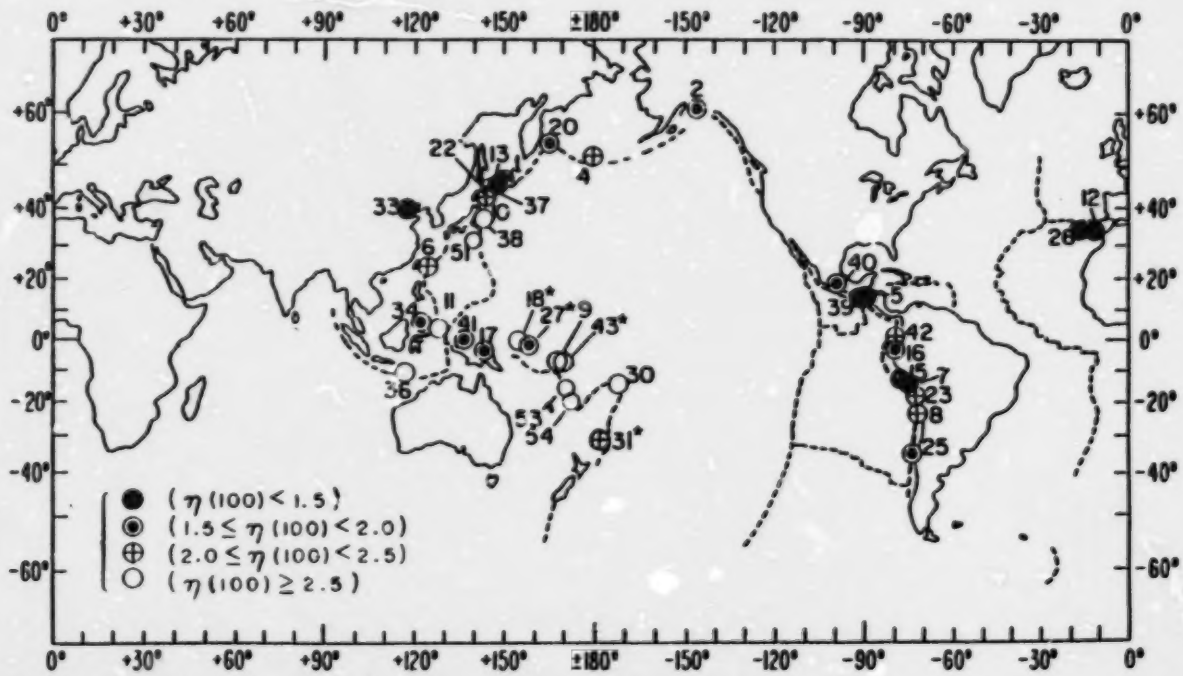
The North China sedimentary basin has been the site of nine large ($M \geq 7$) and destructive earthquakes since 1600 A.D. The hazard from such events would be totally unpredictable if they occurred randomly without any geologic rationale. Wang Ping Chen of the University of Illinois and John Nabelek of the Massachusetts Institute of Technology have interpreted these large earthquakes in terms of the tectonics of an actively subsiding sedimentary basin. They propose that the North China basin has evolved as a composite pull-apart basin due to right-lateral slip on numerous right-stepping faults since the Eocene. By integrating heat flow and other geophysical data with Quaternary depositional patterns, these scientists have provided a physical basis for understanding these earthquake occurrences.

SPECIAL ACTIVITIES

In addition to the primary mission of providing funds for research, NSF supports many important peripheral activities. These activities include extensive international cooperative projects; workshops, conferences and symposia; programs designed to obtain data from actual earthquakes; and special programs with smaller universities, colleges, and industry to increase their participation in research.

International Activities

The international activities are varied and are conducted in a cooperative manner with several countries. The following are representative projects:



One-hundred day areal expansion ratios plotted at the epicenters.

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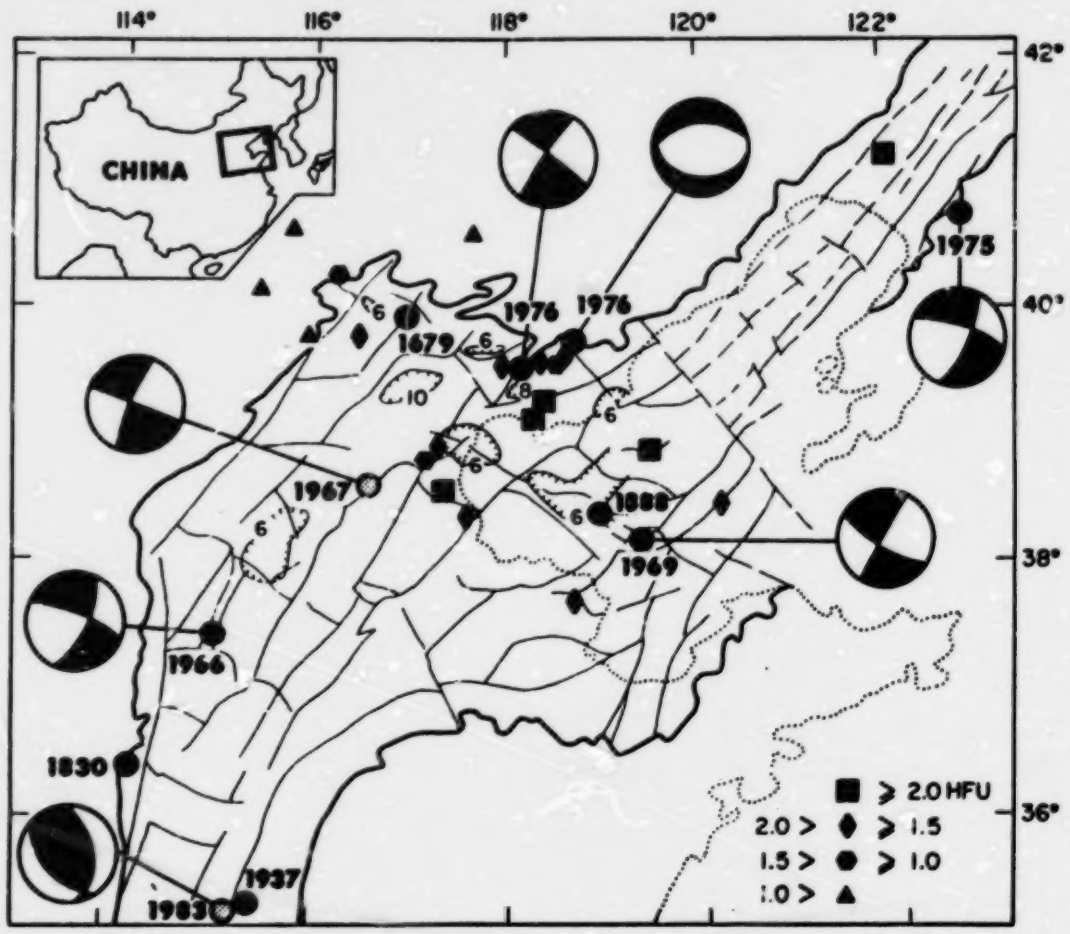

Map summarizing the recent and historical seismicity, heat flow, structure, and sedimentation since the Quaternary of the North China basin. The present boundary of the basin is shown by thick solid lines; known faults by solid lines (dashed when less certain), coastline by dashed curves. Quaternary depocenters are shown as depressions with isopachs of Quaternary sediments (in 100 m) marked. Solid dots are epicenters of large (M≥7) earthquakes since 1600 A.D.

Japan

Under the auspices of the US-Japan Natural Resources agreement (UJNR), the Panel on Wind and Seismic Effects has supported several projects through task committees as follows:

- Experiments on large-scale buildings of reinforced concrete and steel.
- Seminars on repair and retrofit of buildings of reinforced concrete and masonry.
- Seminars on the seismic performance of structures that investigate the effectiveness of various mathematical models.
- Workshops on seismic resistance of bridges.
- Development of a coordinated research project on reinforced masonry buildings.
- Workshop on lifeline systems.

New Zealand

- Joint research project to develop an analysis method based on field experiments of a curved highway bridge using elastomeric bearing supports.
- Joint research project to verify analytical

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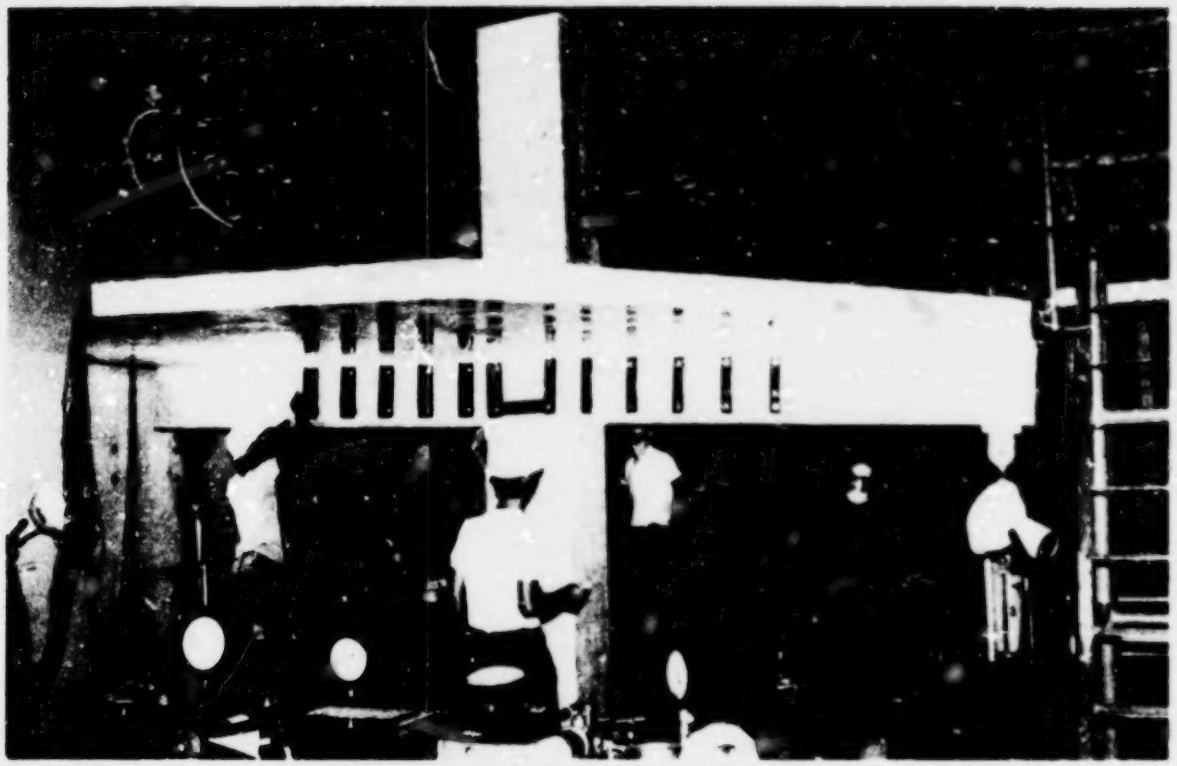

In this National Science Foundation sponsored research project, the University of Texas at Austin is investigating beam to column joints in buildings for resistance to earthquake motions. This project is also being done with cooperation from the University of Canterbury, New Zealand and the University of Tokyo.

methods for traveling seismic wave effects on bridge abutments.

People's Republic of China (PRC)

In 1984, the protocol agreement between the PRC and the United States for technical cooperation in earthquake studies was renewed for five years. NSF is a major participant in the area of earthquake engineering and fundamental studies; to date, this has involved both U.S. universities and Federal research and engineering institutions. The following joint research projects have been completed or are continuing:

- California Institute of Technology and the Institute of Engineering Mechanics, Harbin (PRC): A research project on strong-motion arrays to record strong-motion data in China.
- University of Tulsa and the Pipeline Design and Research Institute, Beijing (PRC), and the University of Oklahoma and the Municipal Engineering Research Institute, Beijing (PRC): Coordinated project work related to field evaulations of earthquake damage to buried pipelines.
- State University of New York and the Geophysical Institute (SSB), Beijing (PRC): A portable, dense array system to analyze the earthquake strong-motion characteristics in the field.
- University of California, Davis, and Institute of Engineering Mechanics, Harbin (PRC): Research on site characterization and instrument measurements of pore pressure for soil liquefaction.
- University of Massachusetts and Institute of Engineering Mechanics (PRC): Joint study on structural design and dynamic analysis of liquid storage tanks.
- University of Illinois, Urbana, and Chinese State Seismological Bureau (PRC): Development of probability bases for earthquake-resistant design.

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- University of Missouri, Rolla, and Harbin Architectural and Civil Engineering Institute (PRC): Aseismic optimum structural design in engineering practice and code provisions.

Taiwan

- The cooperative project between the University of California and Taiwan includes a strong-motion array (SMART-1), which has recorded several strong earthquakes. These data have made it possible to measure and analyze local variations of ground motion. The Electric Power Research Institute (EPRI) has initiated a multi-million dollar research project in conjunction with this strong-motion array to instrument and measure earthquake effects in model special structures.
- Currently, a project to deploy additional instruments and measurement devices for soil response of the array sites is being initiated at the University of California at Davis. This project will augment the existing free-field and EPRI instruments, thus making the project a fully instrumented on-site earthquake laboratory.

India

- A strong-motion array project is being carried out by Lindvall, Richter and Associates in conjuction with the University of Roorkee, India. Fifty strong-motion instruments have been installed in the seimsically active Kangra region.
- Charles Scawthorn of Dames and Moore of San Francisco in collaboration with Jack Benjamin and Associates and the California Polytechnic State University at San Luis Obispo are collaborating with the University of Roorkee. The research includes examining a wide range of components and configurations of unreinforced masonry buildings to provide strengthening techniques to mitigate earthquake damage to low-quality masonry buildings.
- Helmut Krawinkler at Stanford University in collaboration with the University of Roorkee is developing experimental techniques for testing of low-quality masonry. It is expected that these techniques will be employed by Indian researchers for a comprehensive study on the seismic response behavior of houses of adobe and low-quality masonry.

Union of Soviet Socialist Republics (USSR)

- The US/USSR Joint Committee on Cooperation in the field of Housing and other Construction defined topics and forms of cooperation and research within the framework of the working group for Building in Seismic Zones. Research topics of mutual interest include analysis of structural response to earthquakes and development of theory, engineering-seismometric instrumentation and measurements, and experimental investigations of earthquake resistance of buildings and structures. A USSR delegation of six seismic experts visited NSF and several U.S. institutions in May 1986 and conducted fruitful exchanges of technical information on seismic construction.

Yugoslavia

- The United States and Yugoslavia have agreed to continue to pursue cooperative research projects that are important to the mitigation of earthquake hazards in both countries. Research areas that will be explored are seismic vulnerability of modern building structures; and retrofitting and upgrading of brick, masonry, and stone structures.

Workshops, Symposia and Conferences

Each year NSF provides funds to conduct workshops, symposia, and conferences. The objectives of these activities include the determination of research priorities and the dissemination of research results to the appropriate user communities. During Fiscal Year 1986 the following meetings were held:

- U.S.-France Workshop on Quality Guidelines for the Practice of Earthquake Engineering, May 26-28, 1986, Paris, France, M. Agbabian, University of Southern California;
- Second US/Japan Workshop on the Improvement of Building Seismic Design and Construction Practices, August 5-7, 1986, San Francisco, C. Rojahn, Applied Technology Council;

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- Natural Hazards Workshop, Boulder, Colorado, July 20-23, 1986, W. Riebsame, University of Colorado;
- Workshop on Fuzzy Set Applications in Civil Engineering, October 1985; Professor James T. P. Yao, Purdue University;
- Seminar on Base Isolation and Energy Dissipation, March 12-13, 1986, San Francisco, C. Rojahn, Applied Technology Council;
- Workshop on Base Isolation and Passive Energy Dissipation, March 14, 1986, San Francisco, C. Rojahn, Applied Technology Council;
- Workshop on US/Japan Cooperative Masonry Research Project, September 8-10, 1986, Keystone, Colorado, J. L. Noland, University of Colorado;
- Third U.S. National Conference on Earthquake Engineering, August 24-27, 1986, Charleston, South Carolina, James E. Beavers, Earthquake Engineering Research Institute;
- US/Peoples Republic of China Workshop on Seismic Resistance of Masonry Structures, May 18-28, 1986, Harbin, China, D. P. Abrams, University of Illinois; and
- Symposium on 19 September 1985 Mexican Earthquake, October 14, 1985, San Francisco, Earthquake Engineering Research Institute, Roger E. Scholl.

Learning from Earthquakes and Other Hazards Projects

The Earthquake Engineering Research Institute (EERI) continued to conduct post-earthquake investigations of damaging earthquakes in the U.S. and abroad. These post-earthquake audits are designed to acquire field data on the performance of buildings and the socioeconomic impacts of earthquakes. During the past year EERI investigated events which occurred in Ohio (January 31, 1986); Mt. Lewis, California (March 31, 1986); Adak, Alaska (May 7, 1986); and Bishop, California (July 21, 1986). Major foreign events that were investigated earlier were those that occurred in Chile (March 3, 1985) and Mexico (September 19, 1985). The Chilean and Mexican earthquake investigations were jointly undertaken by EERI with the Committee on Natural Disasters, National Research Council (NRC). A report prepared by the interdisciplinary team that investigated the Chile event has been released on mitigation and preparedness issues such as the nature of ground shaking, the response of ground shaking, the response of engineering structures, microzonation, and institutional aspects. A report on the Mexico earthquake is forthcoming.

The National Research Council's (NRC) Committee on National Disasters also organizes teams of field researchers to collect data on the performance of constructed facilities and social systems following various types of disasters. The committee sometimes investigates earthquakes, as it did jointly with EERI in the case of the Chilean and Mexican earthquakes, but it also conducts research on disasters caused by other agents including floods, hurricanes and tornadoes. For example, the impacts of the Nevada del Ruiz Volcanic Eruption that struck Colombia, South America on November 13, 1985, was investigated by one of its teams.

Special Programs

Several special programs also have been incorporated into the research programs of NSF. They include:

- Engineering Research Equipment Grants. This program provides funds for specialized permanent equipment beyond that which is normally available in a university laboratory.
- Presidential Young Investigator Awards. These awards provide cooperative research support for the Nation's most outstanding and promising young science and engineering faculty. This program includes participation by the industrial sector and has the objective of improving the capabilities of universities to respond to the demand for highly qualified scientific and engineering personnel for academic and industrial research.
- Research in Undergraduate Institutions. This program, which supports research in academic settings where the primary emphasis is on undergraduate education and research involvement, is a means of preparing students for graduate studies and careers in engineering and science.

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- Research and Instrumentation at Primarily Undergraduate Institutions. This program supports research in institutions where research implicity or explicitly contributes to the preparation of undergraduate students for entry into docotoral education and careers in engineering research.
- Engineering Research Initiation Grants. This activity provides an opportunity for recently appointed assistant or associate professors to initiate academic engineering research.
- Small Business Innovation Research. This program is designed to stimulate technological innovation in the private sector, increase the commercial application of NSF-supported research results, and improve the return on investment from Federally funded research for its economic and social benefits to the Nation. This is accomplished via awards to science-based and high-technology, small business firms.

FISCAL YEAR 1986 HIGHLIGHTS

Microcomputer Use in State and Local Disaster Preparedness

New technology is becoming increasingly available to professionals in the hazards reduction field. Thomas Drabek at the University of Denver has initiated a study on the patterns of implementation and outcomes of microcomputer use by State and local emergency managers in preparing for and responding to earthquakes and other natural disasters. The project is documenting microcomputer use by State and local emergency managers for disaster preparedness and response, exploring the consequences of microcomputer implementation on the internal functioning of State and local emergency management agencies, and identifying the future needs of such organizations in regards to microcomputer usage.

Data Storage and Retrieval System

In recent years, significant expansion has occurred in the knowledge base in the earthquake hazard mitigation field. As a result, new information systems are needed to facilitate the dissemination and utilization of research results in the area. Harri Prival of Telemechanics, Inc. is developing a prototype data storage and retrieval system for earthquake engineering and related earthquake hazard mitigation disciplines. In developing this system, he is taking advantage of recent advances in the fields of memory technology, data compression, computer graphics and display technology. When completed, the system will allow for the wide dissemination of large volumes of texture and image data at an affordable cost to users.

Measuring Earthquake Impacts and Recovery

Decision makers are hampered by the lack of a commonly accepted measuring instrument for assessing the social and economic impacts of earthquakes and other kinds of disasters that occur in the U.S. and other parts of the world. In a project at the University of Georgia, Frederick Bates and his research team are designing such an instrument which can be used on household level domestic assets. When completed, the measuring scale will have cross-cultural validity and will give policy makers a tool which has some of the same significance that the Richter Scale has for physical scientists. The new scale will make it possible to compare the magnitude of disasters occurring in different parts of the world in social and economic terms and to more effectively monitor the recovery process as it takes place over time, since it will be possible to take measurements during various phases of reconstruction and recovery activity. New data is now being incorporated into the study related to the recent Mexico earthquake.

Dissemination of Research Results

NSF continues to disseminate research results to users and to cooperate with other relevant agencies in such activities. The dissemination efforts are aimed at diverse audiences, including engineers, architects, building officials, government officials, and researchers. Numerous channels of communication are used to inform users of relevant research results. The Natural Hazards Information Center and the National Information Service for Earthquake Engineering are the centerpieces of the dissemination program.

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The Natural Hazards Information Center at the University of Colorado receives support from NSF as well as funding from the U.S. Geological Survey, the Federal Emergency Management Agency, National Oceanic and Atmospheric Administration, National Institutes of Mental Health, Environmental Protection Agency, and the U.S. Army Corps of Engineers. The center reaches several thousand hazards and disaster specialists in government, business, and the research community through its bimonthly publication, the *National Hazards Observer*, which summarizes recent research results and discusses hazards research applications and programs. Research results also are disseminated by researchers to emergency managers and decision makers at the Center's annual hazards workshop.

NSF also continues to support the National Information Service for Earthquake Engineering (NISEE). With components located at the University of California, Berkeley, and the California Institute of Technology, NISEE disseminates earthquake engineering and related information through library services, computer software, and publications, including the *Abstract Journal in Earthquake Engineering*. NISEE distributes computer programs developed from analytical procedures and verified when possible by experimental methods. This activity has been instrumental in providing practitioners with the tools to design safer and more economical buildings of all types.

Another example of NSF's dissemination program is a project it funded at the American Institute of Architects' Research Foundation to design seismic safety workshops for architects and other building professionals. The specific objectives of these workshops were:

- To develop an awareness and comprehensive understanding of the nature of earthquakes in vulnerable areas;
- To explore professional roles and responsibilities in earthquake resistant design and hazard mitigation efforts; and
- To learn state-of-the-art seismic design techniques that can be incorporated directly into professional practice.

Research on March 3, 1985, Chilean Earthquake

The Chilean Earthquake which occurred offshore of central Chile caused strong shaking in the coastal cities of San Antonio, Valparaiso, and Vina del Mar, and inland to the capital, Santiago. An estimated $2 billion in damage occurred with 176 persons reported killed, about 2,500 persons reported injured, and thousands reported homeless.

A joint EERI and NRC team arrived in Chile on March 7, 1985, and remained there several days to study the impacts of the disaster. The field team was led by Loring Wyllie of H. J. Degenkolb Associates and included persons from such disciplines as lifeline, geotechnical, and structural engineering, and the social sciences. Several other investigators from the U.S. coordinated with the EERI/NRC team, which brought the team of cooperating researchers studying the earthquake to a total of 15. A report was prepared on the results of the field study.

EERI organized and held a briefing on the Chilean field investigations at the U.S. Geological Survey in Reston, Virginia, on July 18-19, 1985. Over 200 persons attended the briefing and heard reports on the seismological aspects of the earthquake; the performance of buildings, industrial facilities, bridges and lifelines; and reports on architectural, socioeconomic, and health care aspects. Topics for future research on this earthquake were identified at the conclusion of the briefing.

As a result of the EERI briefing, research proposals were received by NSF to perform research related to this earthquake which has implications for and application to earthquake engineering in the United States. In a cooperative effort with the USGS, NSF made eight research grants to learn from this important seismic event.

Masonry Research Program

A cooperative research project with Japan on the seismic resistance of masonry buildings has been initiated. This activity is coordinated

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with a similar project by the Building Research Institute of Japan as part of the continuing activity of the Task Committee on Large-Scale Experiments of the Panel on Wind and Seismic Effects under the U.S.-Japan Cooperative Program in Natural Resources agreement. The U.S. research program consists of a series of coordinated research tasks beginning with tasks which address basic material behavior, progressing to tasks addressing behavior of masonry structural components such as walls, to experiments on a full-size research building. Development of analytical methods for stress and strain analysis and system behavior will proceed in parallel with experimental tasks. The final task will be the preparation of recommendations for design procedures and building code provisions.

Research on the 19 September 1985 Mexico Earthquake

A magnitude 8.1 earthquake struck Mexico in the morning of September 19, 1985. Numerous buildings designed under building code standards comparable to those used in parts of the United States were severely shaken — both in the epicentral region along the Pacific Coast and in Mexico City. In both areas strong motion instruments provided some coverage of the ground motions and of the effects of local soil and geological conditions upon these motions. There were many instances of collapse or severe damage of structures as well as many examples of excellent performance. Lifeline systems were put to the test. Emergency response procedures were severely strained. In short, this earthquake significantly tested earthquake hazard mitigation practices.

As part of NSF's existing programs, quick response teams assembled by the Earthquake Engineering Research Institute and the National Research Council were dispatched to the earthquake area to document highly perishable engineering information. They reported back on possible research actions following their reconnaissance work. A public briefing meeting on the reconnaissance work was held on October 14, 1985, to discuss possible follow up actions required to maximize learning from the earthquake. This meeting was held in San Francisco and was attended by over 600 persons.

A joint panel was formed by the National Research Council and the Consejo Nacional de Ciencia y Tecnologia to prepare a joint report detailing potential research topics of importance in order to learn lessons from the experience with this earthquake. Unsolicited proposals were encouraged by NSF engineering based on this report. NSF made 28 awards to U.S. investigators under this program. These projects are identifying lessons that can be learned from the Mexico earthquake experience that have relevance to mitigation and preparedness in the U.S. The investigators are also working cooperatively with Mexican counterparts.

Earthquake Engineering Research Center

During the 1986 Fiscal Year an Earthquake Engineering Research Center was established at the State University of New York (SUNY), Buffalo. The Center is a cooperative $10 million per year research operation with NSF providing $5 million per year and the matching balance provided by the State.

Although the award is to Buffalo, which will serve as a focal point for the Center's activities, the new facility will involve the coordinated efforts of the City College of New York, Columbia University, Cornell University, Lamont-Doherty Geological Observatory, Lehigh University, Princeton University and Rensselaer Polytechnic Institute. The center will be directed by Dr. Robert L. Ketter, Leading Professor of Engineering and Applied Sciences.

The Center will conduct research to improve basic knowledge about earthquakes, engineering practice and the implementation of seismic hazard mitigation procedures to minimize the loss of lives and property. The Center also will be a national focal point for earthquake engineering research and enhance the international competitiveness of the U.S.

Major areas of study initially will be directed toward buildings and other structures built before the need to mitigate the effects of earthquakes was realized. Emphasis will be given to a systems approach in which earthquake requirements are integrated with consideration of other hazards such as high winds.

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NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards (NBS) earthquake program addresses 2 problem areas: safe and economical new construction, and assessment and mitigation of hazardous existing facilities.

It is important that new construction not add to the earthquake problem. Safe and economical new construction may be achieved by improved, nationally applicable seismic standards. Structural, geotechnical, mechanical, architectural, and economic studies performed or supported by the National Science Foundation and other organizations have produced substantial advances in abilities to model and predict the earthquake response of various built elements. This knowledge, however, must be synthesized to develop design criteria that will provide consistent levels of safety among the various built elements, independent of the materials or technologies used. Moreover, design criteria must be developed to fit methodologies appropriate to the responsible design profession. Evaluation and measurement methods consistent with practices of design, manufacture, construction, and inspection must be developed to implement the design criteria. Since existing hazardous buildings are probably the greatest source of danger to the population during a severe earthquake, it is also necessary to develop techniques with which to identify the most hazardous buildings, to develop nondestructive methods to determine the properties of the buildings and their components in place, and to define the strength and energy-absorbing capacity provided by various techniques of strengthening and repair.

To address these issues, the NBS program was established to improve building design and construction practices by conducting fundamental research necessary to establish reliable predictions of the performance of buildings during an earthquake; to provide technical support in the development of seismic design and construction standards for Federal construction; and to encourage the adoption of improved seismic provisions in State and local building codes. Currently, the major thrusts of the NBS earthquake program are (1) improved design criteria and standards, (2) more reliable measures of the effects of natural forces on buildings, (3) safety evaluation of existing buildings, and (4) postdisaster investigations.

The NBS laboratory research program is designed to provide information on which to base advanced structural design criteria for improving seismic behavior of new or existing building structures. It is aimed at meeting the most urgent research needs to fill the gaps in building codes and standards, developing new criteria, and making recommendations for repair and retrofit of existing structures. The research is conducted in cooperation with other Government agencies, practicing engineers and architects, professional organizations, trade associations, building owners, product manufacturers, standards and regulatory organizations, and university researchers. In planning this work, close liaison is maintained with these individuals and organizations. These interactions assist in identifying and assigning priorities to research problems in earthquake engineering. They also ensure that NBS efforts are coordinated with other work.

RESEARCH ACTIVITIES

Strength design of masonry walls to resist earthquakes has been identified as an area in which there is a serious deficiency of supporting research. The NBS/Building Seismic Safety Council Overview Committee for seismic design provisions and others have indicated that research is needed to substantiate and improve the current code provisions for determination of shear wall resistance to earthquakes.

Fiscal Year 1986 saw the completion of the first phase of a research program begun in Fiscal Year 1984. The overall research program has an objective to define the shear capacity and behavior of masonry walls. The first phase was devoted to unreinforced, hollow concrete block walls. The parameters studied include vertical compressive stress, wall aspect ratio (wall length to height), block strength, mortar type, and external flexural reinforcement. A total of 49 wall panels were tested in phase 1. The wall panels were subjected to in-plane displacements in combination with vertical

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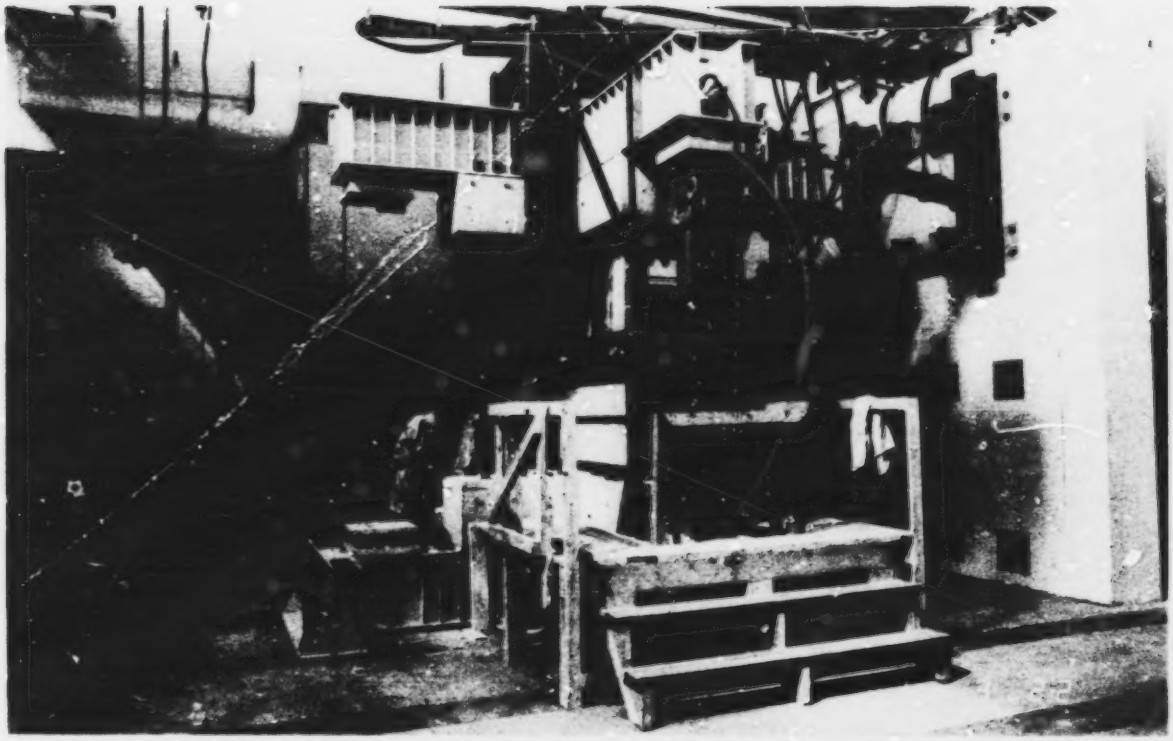

A concrete block masonry wall is being placed in the NBS Tri-Directional Testing Facility, a computer-controlled testing facility. The wall will be tested to failure under constant vertical force and reversed cyclic in-plane force as part of a research project on the shear resistance of masonry walls.

compression stresses using the unique NBS Tri-directional Test Facility (TTF). The TTF, a totally computer-based test system, imposes well defined boundary conditions on the wall, greatly improving the repeatability of the tests. The resulting data indicated that the influence of vertical compressive stress on wall lateral load capacity was nearly linear and that the maximum resistance was best defined by a single, consistent measure of response, diagonal tension strain.

The results of phase one will be incorporated into recommendations for the design of masonry wall elements and submitted to the national building design standards development groups. In addition, the information will serve as benchmark data for tests in future phases of the program and will provide guidance in the planning of future research.

A two-year program on reinforced masonry was planned in Fiscal Year 1986 and fabrication of test specimens was started in the summer. This next phase will explore the influence of reinforcement quantity and arrangement on the shear resistance of masonry walls.

A second experimental program in progress at NBS will study the behavior of connnections in braced multistory steel frames. The program was developed in cooperation with the American Institute of Steel Construction's Task Group on Bracing for Heavy Construction.

Multistory steel frame buildings frequently use a diagonally braced core to provide stability and to resist both earthquake and wind forces. It is common in such bracing systems to use steel plates (gusset plates) to connect the diagonal braces to the beams and columns. The force distribution in these plates and the force transmitted to the connecting members is complex and influenced by many factors which have not been experimentally verified.

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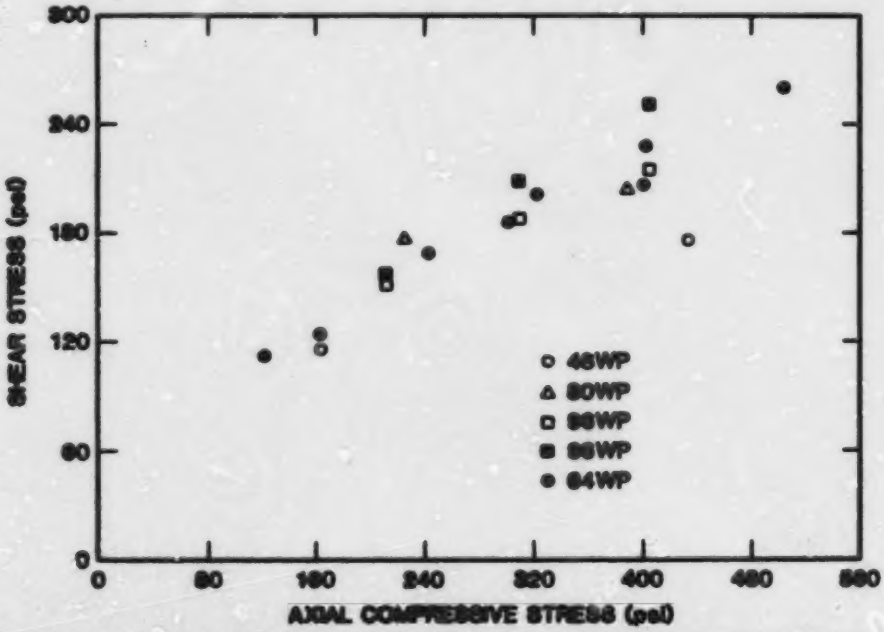
The seismic shear resistance of this unreinforced masonry wall is being determined experimentally using the Tri-Directional Testing Facility. A constant vertical force is being applied while the wall is moved back-and-forth in the horizontal directional direction to simulate earthquake motion.



Influence of vertical compression force (stress) on the seismic shear resistance of masonry wall panels. Wall panels are 48-inches high and 48-, 64-, 80-, and 96-inches long. The relationship is nearly linear.

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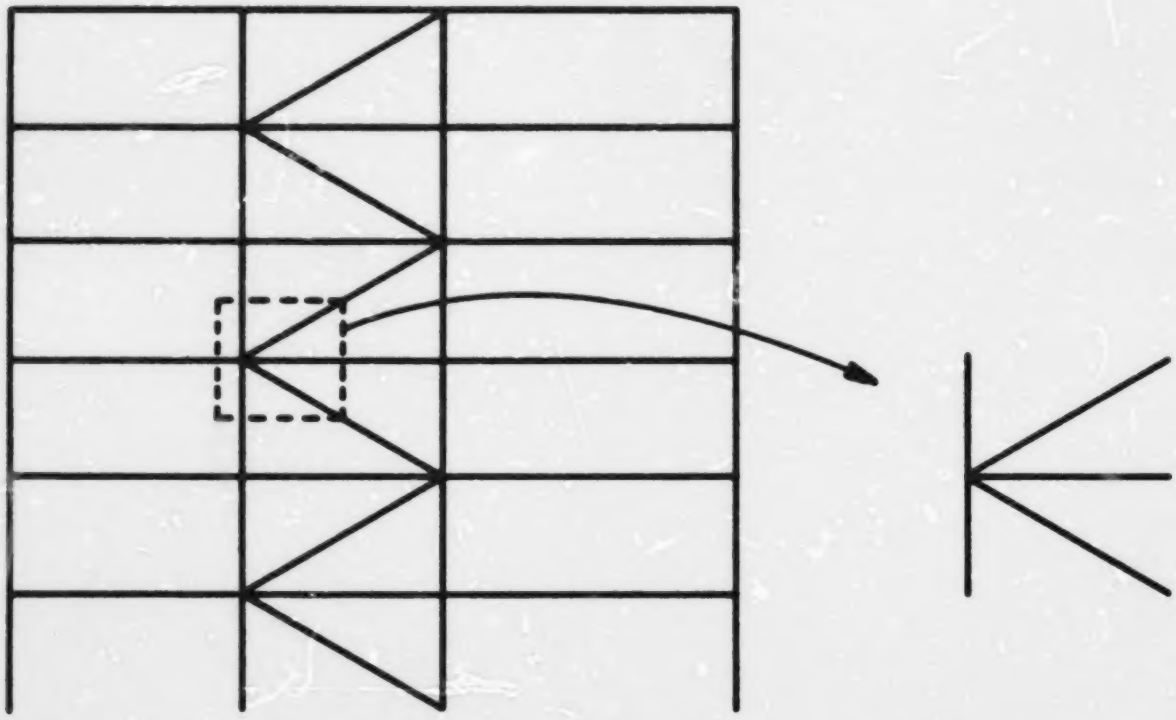

A schematic of the braced core in a multistory steel building is shown in the figure on the left. The subassemblage used as a test specimen is shown on the right. The subassemblage models the behavior of the critical portions of the frame.

A portion of a multistory frame (a subassemblage) will be tested in the laboratory to study:

- the extent to which the distribution of forces within a gusseted connection is influenced by the members framing into the connection;
- the difference in forces generated in two connections: one in which the axes of the beams, columns, and diagonals intersect at a single point and one in which they do not, thereby introducing an eccentricity; and
- the difference in force distribution between connections with columns oriented differently.

The subassemblage will be tested in the previously described Tri-directional Testing Facility. Test boundary conditions will model those in the prototype building as closely as possible. The test specimens will be about three-quarters of the size of typical building members.

Large-scale testing is an important component of the structural laboratory work. Current work on large bridge columns will extend understanding of the performance of very large structures and will provide data that are not currently available. Both full-scale performance at large deformations and the effect of specimen size on test results are being studied to determine if research on small specimens can be safely extrapolated to the large sizes actually being used in bridges and to the large deformations expected in a severe earthquake.

One large-scale column 5 feet in diameter and 30 feet high, reinforced with twenty-five 1.7 inch diameter reinforcing bars has been tested. The column was subjected to cyclic lateral displacements up to 2 feet while supporting vertical load simulating the weight carried by the columns. A second test which will include repair of the column is scheduled for Fiscal Year 1987.

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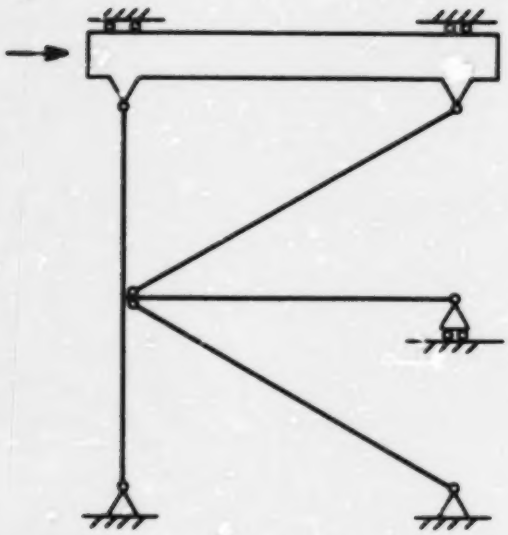
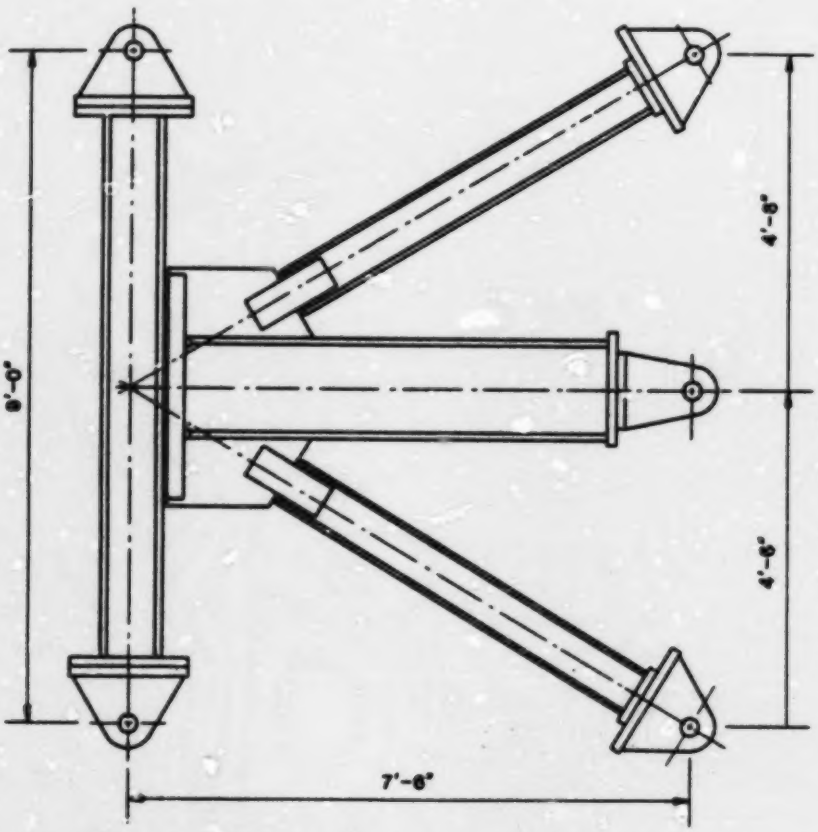


A schematic of the subassemblage with the boundary conditions required to simulate the behavior in the full frame is shown. The Tri-Directional Test Facility will be used to model the boundary conditions.



The structural shapes and dimensions are shown. The subassemblage is about three-quarters of the size of members and spans used in "typical" frames.

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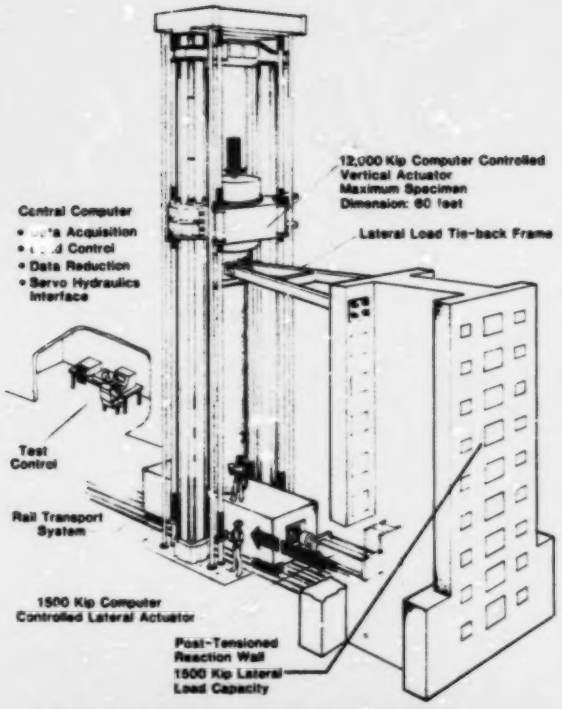

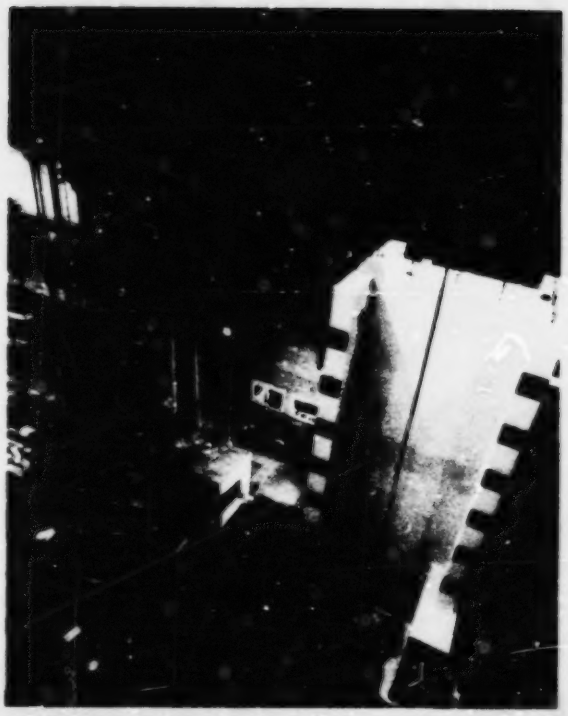

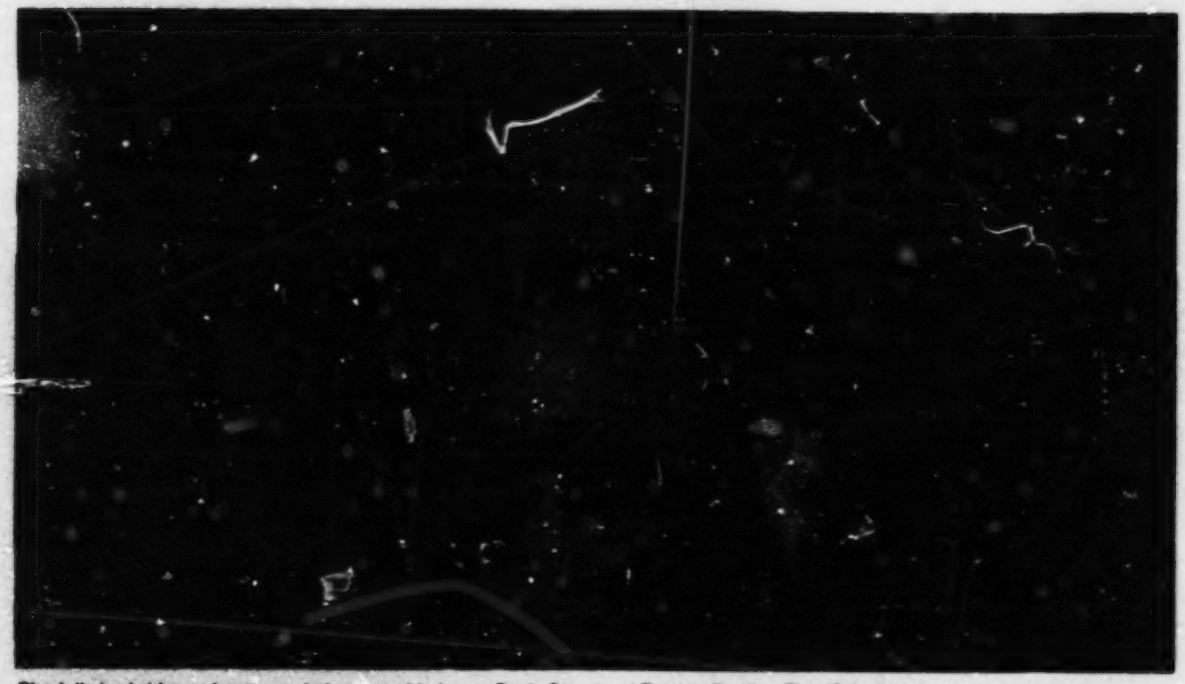

The full size bridge columns are being tested in Large-Scale Structural Testing Facility. The 45-foot high reaction wall is shown along with the 12-million pound capacity testing machine. Vertical loads are applied using a 1.5-million pound actuator with a 4-foot piston stroke. A column under test is visible in the testing machine. Components of the facility are identified in the schematic drawing.

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A full-scale bridge column is shown at two-feet of lateral displacement. Fractured reinforcing is visible in the close-up near the base of the column. The 5-foot-diameter column is 30 feet in height and believed to be the largest tested under laboratory conditions. The column is reinforced with twenty-five 1.7-inch diameter reinforcing bars. Over 100 sensors are measuring the response of the column.

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A companion series of six 1/6-scale structural models have been tested, using the TTF, as part of the program to study scale effect. This work is being supported by the NBS, NSF, Federal Highway Administration (FHWA), and the California Transportation Department.

NATIONAL EARTHQUAKE ENGINEERING EXPERIMENTAL FACILITY

In 1984 the National Research Council published the results of its 6-month study on "Earthquake Engineering Facilities and Instrumentation" requested by the Office of Science and Technology Policy (OSTP). One of the major recommendations of the report was that "The Federal government should undertake, on an accelerated basis, planning aimed at developing a major national earthquake engineering experimental/test facility. The goals of that facility should be to provide the data and understanding necessary for rapid improvement in the design and construction of seismic-resistant structures."

The Science Advisor to the President urged FEMA to initiate the planning study called for in the NRC report to develop the information which can be used as the basis for a decision on the need for and the requirements of a national earthquake engineering experimental facility. At the request of FEMA the Policy Coordination Group of the National Earthquake Hazards Reduction Program (NEHRP) analyzed the planning study in terms of its scope and funding alternatives.

The Policy Coordinating Group recommended proceeding with the planning study, to be conducted by the National Bureau of Standards (NBS). The initial phase of the study started in late Fiscal Year 1985 with joint funding by FEMA and the NSF.

The objectives of the study are to:

- define the data needed on full-scale structural behavior;
- define the large shake table, etc., needed to obtain data;

A 1/6-inch scale model of the full-scale column is shown under test in the Tri-Directional Testing Facility. Reinforcing bars are about 1/4-inch diameter in the model.

- define siting, operational, and cost requirements;
- assess cost effectiveness with respect to alternative data sources; and
- achieve credibility of the findings and recommendations in the professional, earthquake, scientific, and national policy communities.

The current year of the study is addressing research needs and priorities. This includes determination of critical data needs on full-scale structural performance and development of a multi year experimental/test program with facility requirements. Subsequent phases will include studies of engineering design, and siting, operational and management requirements.

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A workshop is scheduled for the fall of 1986 to review proposed needs. The final report is due in early 1987.

IMPROVED SEISMIC PRACTICES

The NBS has worked closely with FEMA in establishing and supporting the Federal Interagency Committee on Seismic Safety in Construction (ICSSC) and in participating in the non-Federal Building Seismic Safety Council (BSSC) activities. These efforts have led to considerable resource material for improving seismic design provisions for building codes and standards and practices for both private and Federal construction.

The ICSSC, chaired by the NBS, currently is examining a number of problems of importance to the Federal Government, including studies on the use of a uniform seismic design standard (and selection of recommended provisions) by Federal agencies, work on existing buildings, protection of lifelines, and response of the ICSSC to damaging earthquakes. In addition to its role as Chair, the NBS is providing technical support for these activities. The NBS and the ICSSC are cooperating with the BSSC; ICSSC members participate on BSSC technical committees and Board.

At the request of FEMA, the NBS has provided technical studies throughout the BSSC's program on improving seismic design provisions. With financial support from FEMA, the NBS provides the technical secretariat to the BSSC Overview Committee in its efforts to evaluate seismic provisions being studied by the BSSC. The seismic provisions being considered were originally prepared by the Applied Technology Council in 1978 in a major project sponsored by the National Science Foundation and the NBS. The seismic design procedures were proposed to the BSSC and were balloted by its membership in the fall of 1984. The Overview Committee reviewed the ballot results and prepared revisions to resolve issues raised by the ballot. BSSC balloted and approved the procedures in November 1985. The three volume document, *NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings* has been printed by FEMA and has been made widely available. An update effort is now underway and due for completion in 1988. NBS will continue to work with the BSSC in this effort.

POST DISASTER INVESTIGATIONS

On September 24, 1985, the NBS and U.S. Geological Survey (USGS) dispatched a team of investigators to Mexico City to provide technical assistance to the U.S. Embassy under the auspices of the Agency for International Development (AID), Office of the United States Foreign Disaster Assistance (OFDA). The team also reviewed the performance of engineered structures to assist in the improvement of U.S. seismic design and construction practices. The team advised U.S. rescue workers and Mexican officials on means to more rapidly remove debris from collapsed buildings to speed the search for survivors, and worked with Mexican experts to identify fruitful opportunities for in-depth studies of structural performance.

The team representatives also briefed the U.S. Ambassador to Mexico and his staff on the earthquake. This included cause of the earthquake, possible reasons for such large ground motions, and possible reasons for the observed structural failures.

Preliminary observations indicate that the primary causes of structural failures were unusually high accelerations combined with an exceptionally long duration of shaking. The high accelerations were caused by amplifications due to local soil conditions. The coincidence of the period of ground shaking with the natural period of a large number of buildings, and foundation failures due to loss of soil shear capacity led to catastrophic damages.

Dissemination of the observations from post-earthquake reconnaissance surveys is an important means for communicating information on building performance to the engineering profession. Efforts already are underway. NBS staff participated with engineers from Mexico City in a special session on the Mexican earthquake on October 22, 1985, at the American Society of Civil Engineers (ASCE) Annual Meeting in Detroit. The NBS presentation concentrated on the structural aspects of building performance, illustrated

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various types of building damage, and discussed causes of failure. Information on the earthquake and on building performance collected by the NBS/USGS team has been compiled in a video tape that is available for use by interested parties. NBS also worked with the research community to plan an agenda of needed research.

INTERNATIONAL ACTIVITIES

The U.S./Japan Panel on Wind and Seismic Effects provides for cooperative activities of 15 U.S. agencies and nine Japanese agencies and participating representatives of private sector organizations. NBS provides the U.S. -side chairman and secretariat. The Panel conducts an annual technical conference, alternating between the U.S. and Japan. The 1986 conference was hosted by the U.S. The one-week technical conference was held in Washington to discuss recent research results. The results were presented in 21 U.S. papers and 20 Japanese papers. A one-week technical study tour of laboratories and construction projects followed the technical meeting.

A special workshop will be held on the joint U.S.-Japan Large-scale Testing Program in Denver, Colorado, during the fall of 1986. The Task Committee on Disaster Prevention Methods for Lifeline Systems participated in the 3rd Annual Conference on Earthquake Engineering during August 1986 in Charleston, South Carolina. Five workshops are planned for the coming year. The Panel continues to plan for data exchange and cooperative investigation of earthquake mechanisms, ground motion, and structural performance in important Japanese and U.S. earthquakes.

Other international cooperative programs include:

- a cooperative program with the French national laboratory for building research (Centre Scientifique et Technique du Batiment), which includes an information exchange project on seismic repair and retrofit of existing buildings,
- cooperative programs with Yugoslavia on seismic design criteria, including the criteria being evaluated by the BSSC, masonry shear wall resistance to seismic loading, bridge columns, and potential of soils to liquefy.

The International Council for Building Research, Studies and Documentation (CIB) provides for international cooperation in research and improvement of building practices. Topics of structural safety, timber structures, actions on structures, wall structures and earthquake hazard reduction are particularly relevant to the U.S. earthquake hazard reduction program. NBS facilitates effective U.S. participation in these CIB programs as a CIB full member and through individual membership in working commissions and participation in CIB management. NBS also participates as a titular member in the International Union of Laboratories for Research and Testing of Materials and Structures (RILEM). RILEM has established a technical committee for international cooperation and development of test methods for seismic resistance of structures.

IMPLEMENTATION

The success of Federal programs in reducing earthquake hazards can be measured in terms of the extent to which the results are used by various mission agencies and private sector building owners and users and the extent to which the results are incorporated in new standards and improved design practices. The working relationships that the NBS has established with groups throughout the building community provide an effective means for achieving this implementation. NBS staff members participate actively in standards development in the private sector as well as at Federal, State, and local levels, with over 44 staff members participating in 175 distinct standardization activities. These implementation and coordination efforts have resulted in the adoption of research findings in standards and codes.

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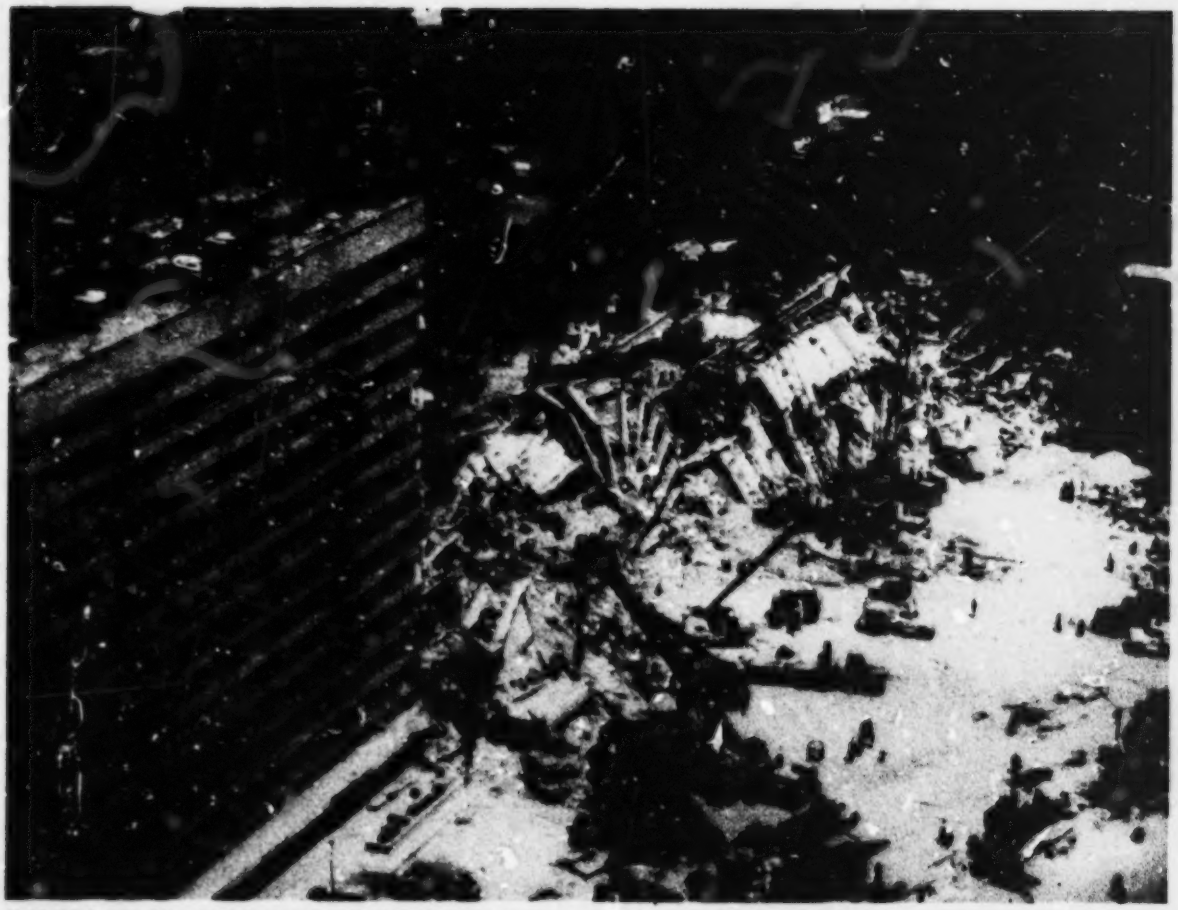
CONTRIBUTING AGENCIES



1985 Mexico earthquake. The 14-story reinforced concrete frame, Nuevo Leon building, consisted of three independent wings separated by construction joints. Two wings, each containing 196 apartments, collapsed with large loss of life.

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AGENCY FOR INTERNATIONAL DEVELOPMENT, OFFICE OF U.S. FOREIGN DISASTER ASSISTANCE

The Agency for International Development, Office of U.S. Foreign Disaster Assistance (AID/OFDA) has supported overseas activities in earthquake hazards reduction in the developing world since 1979. The OFDA disaster preparedness program includes national and regional seismic network development, volcano monitoring and hazards analysis, warning systems, regional earthquake risk mapping, mitigation, and related training. This program reflects the importance AID places on assisting host countries toward achieving greater self-sufficiency as a means of reducing the disaster death toll resulting from geological hazards.

The goal of OFDA's earthquake hazards reduction activities is to reduce probable death and human suffering caused by earthquakes, volcanos, and tsunamis. This is being accomplished by assisting disaster-prone countries to increase their technical competence and civil preparedness organizational skills. Through disaster avoidance and mitigation strategies, this program can reduce the vulnerability of populations to both primary and secondary disaster impacts.

The following objectives will be accomplished by OFDA by the end of 1987:

- Increased leadtime for seismic-related disaster early warning and contingency planning (that is, earthquake forecasts from probabilistic assessments of seismic potential) for selected countries.
- Early warning systems output integrated with hazard reduction activities, host country civil preparedness, and AID development objectives for selected countries.
- Upgraded and integrated foreign national and regional geophysical monitoring networks; cataloged historical seismic data by region and regional risk mapping.
- Evaluation of the relative vulnerability of the developing countries to earthquakes and the development of regional and national mitigation and preparedness strategies in cooperation with participating governments and institutions.
- Strengthening of selected Third World seismological institutions and orientation of foreign scientists and emergency management officials in the application of new technologies for disaster mitigation.
- Comprehensive earthquake engineering orientation programs available to selected high-risk regions.

Results of these activities will continue to be directed toward the establishment of a comprehensive U.S. strategy for international volcano and earthquake hazards mitigation and disaster preparedness. From Fiscal Year 1985 to the present, AID/OFDA has completed the following major activities related to geological hazards reduction in the developing countries:

- Comprehensive evaluation of seismic risk in the Tonga-Fiji-Vanuatu region of the Southwest Pacific.
- Central Peru automatic earthquake location and strainmeter network for forecast analysis and evacuation planning.
- Near-shore tsunami warning system for central Chile utilizing satellite telemetry.
- Earthquake risk mapping and neo-tectonics mapping of the Andean Region for comprehensive disaster planning and development.
- Installation and operational support of national earthquake monitoring systems and hazards reduction activities in Panama, Guatemala, Ecuador, El Salvador, Dominican Republic, and Costa Rica.
- Installation of volcano monitoring and warning systems in Colombia, Indonesia, Papua New Guinea, the Phillipines, and Mexico.
- Establishment of the Volcano Crisis Assistance Team (VCAT) for the Latin America Region in cooperation with the U.S. Geological Survey.
- Completion of the earthquake hazards mitigation program in Southeast Asia in cooperation with the U.S. Geological Survey.
- Completion of the draft uniform building codes for wind and seismic effects in the Leeward Islands of the Caribbean.

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- Strengthening national disaster preparedness and emergency management in Indonesia in cooperation with the U.N. Development Program (UNDP).
- Completion of the circum-Pacific comparative earthquake/tsunami probability analysis for comprehensive contingency planning.
- Establishment of the Southeast Asia Regional Disaster Management Training Center at the Asian Institute of Technology in Bangkok.
- Development of a comprehensive international program strategy for earthquake hazards mitigation in cooperation with the Earthquake Engineering Research Institute in preparation for the International Decade for Natural Hazards Reduction.
- Completion of the Natural Hazards Risk Assessment and Disaster Mitigation Pilot Project for Latin America and the Caribbean in cooperation with the Organization of American States (OAS).

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BUREAU OF RECLAMATION

The Bureau of Reclamation (USBR) earthquake hazard reduction activities basically involve seismic analyses and the concomitant designs or modifications of embankment and concrete dams and large appurtenant structures. In order to accomplish these seismic analyses, a wide variety of state-of-the-art technical studies is necessary. These studies include regional and local seismotectonic investigations; microseismic monitoring; subsurface drilling and trenching explorations; materials sampling and testing programs; and various types and levels of dynamic analyses, including risk-based analyses. The studies peripherally include the installation of field instrumentation and the development of a wide latitude of seismically-related research programs.

In order to maintain awareness of nationwide public issues dealing with earthquake hazards reduction and to continue an aggressive policy of dealing with earthquake hazard issues, USBR supports, participates, and seeks participation in numerous panels, committees, and study groups. This participation involves USBR in local, national, and international earthquake hazard issues.

SAFETY OF DAMS PROGRAM

USBR dams are geographically restricted to the 17 Western States, and most of USBR's seismic programs, analyses, and related work have been in this area. However, USBR's responsibility, acquired in 1980, for the Department of the Interior's (Interior) Safety of Dams Program has now involved USBR in seismic issues throughout the contiguous 48 States. There are, at present, 370 USBR and other Interior dams in Interior's Safety of Dams Program.

A SEED (Safety Evaluation of Existing Dams) report is being made for each of these 370 dams. The SEED report consists of a site examination report including safety of dams, related recommendations, and technical analyses of various issues which lead to a safety of dams classification. Earthquake assessments, liquefaction potential and dynamic analyses are some of the technical analyses performed. The SEED report is completed with an MDA (Modification Decision Analysis) which recommends modifications for those structures which have verified deficiencies that adversely affected the integrity of the structure under consideration.

To date, 170 SEED reports have been completed. Earthquake assessments for these reports require lead time since other analyses depend on the conclusions. Presently, 206 earthquake assessments have been completed or are in final draft. Often, further study beyond the SEED report level is required; there are 102 advanced seismotectonic studies completed for USBR dams.

Currently, USBR has identified about 70 dams which may require modifications for safety reasons; however, most of these safety issues are not associated with earthquakes. Safety modifications have been completed on eight dams.

SEISMOTECTONIC STUDIES

The focus of USBR seismotectonic studies is to provide a site-specific evaluation of significant potential earthquake hazards for engineering analyses. These studies use as an initial basis regional and national-scale, published and unpublished information generated by other Federal and State agencies, universities, and private sector firms and consultants. Additional field and office or contracted studies are then conducted to refine these data and identify the most significant hazards to specific dam or structure sites.

Since 1978, USBR has instituted programs of intensified seismotectonic study as parts of investigations. These studies have concentrated on new construction and on dams prioritized through the safety-of-dams programs. Geographically, these studies have been mainly distributed throughout the 17 Western States.

The scope of USBR seismotectonic programs includes, on a damsite-specific basis, an evaluation of maximum credible earthquakes (MCE's), surface faulting hazards to project

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facilities, and the potential for other seismically induced hazards such as liquefaction and landslides. These studies involve a comprehensive evaluation of the geologic and seismologic evidence for potential earthquake activity of significance to the specific damsites of interest. These studies are accomplished by in-house staff, contract staff, and cooperative agreements with Federal and State entities.

Geologic aspects of the seismotectonic programs focus on evaluations of evidence for young faulting by conducting studies of Quaternary geology and soil stratigraphy, geomorphology, and regional structural and tectonic analyses through office and field investigations. Field investigations often include detailed geologic analyses of faults and landforms to assess the past history of earthquake occurrence. These studies often allow estimates of the size and frequency of paleo-earthquakes to be combined with the record of historic earthquakes in a region, thus extending in time the record from which hazard evaluations are made.

Seismology aspects of the seismotectonic programs focus on evaluation of historic earthquake data, analyses of data from short- and intermediate-term microearthquake monitoring networks, and integration of the results of these analyses with geologic data. These studies provide information on the contemporary state of stress in a region, rates of stress release through earthquakes, the relationships of stress release to known faults, and characteristics of local and regional earthquakes which are significant in the development of ground motions for use in engineering analyses of specific structures.

During Fiscal Year 1986, USBR completed major seismotectonic evaluations for three dams in Central Utah (Joes Valley, Huntington North,

USBR seismotectonic program in west central Oregon involves the investigation of fault scarps such as the one shown striking from the left center to right center of photograph. The surface on the high side of scarp provides attractive sites for homes.

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and Scofield), two dams in Wyoming (Meek's Cabin and Stateline), three dams in Arizona (Senator Wash, New Waddell, and Stewart Mountain), and a study centering around the Central Utah Project which includes more than 20 existing dams. Major seismotectonic studies were initiated in the states of New Mexico, Wyoming, Oregon, and Washington. In addition, over 20 limited scopes evaluations were completed for USBR SEED reports and for construction and modification studies.

SEISMIC MONITORING

During Fiscal Year 1986, USBR continued support to the University of Nevada for the operation of a 7-station local seismograph network in the Lake Tahoe region, California-Nevada. Data from this local network have been incorporated into USBR seismotectonic studies for Stampede, Prosser Creek, Boca, and Lake Tahoe Dams in east-central California. The area covered by the monitoring includes the sites of magnitude 5-1/2 to 6 earthquakes in 1948 and 1966 and several faults considered capable of causing earthquakes, and therefore of considerable significance to USBR dams in the area.

USBR continued its cooperative efforts with the USGS in supporting three local seismograph networks totaling 38 stations in the Sierran foothills and the Shasta area of California, and two networks totaling 16 stations in southwestern Colorado. Data from these networks are being used in various studies for nearby USBR dams and for evaluation of reservoir-induced seismicity.

During Fiscal Year 1986, USBR completed installation of a 16-station network in the vicinity of Jackson Lake Dam, Wyoming. The network was fully operational in May 1985. Data from the network will aid in the evaluation of seismicity in the region and allow timely response to local events.

In Fiscal Year 1986, USBR, in cooperation with the USGS, also initiated a local seismograph network around Monticello Dam in northern California. This network is expected to aid in the resolution of fault activity, seismic sources, and induced earthquake issues.

USBR SEISMIC DAM DESIGN AND ANALYSIS — EMBANKMENT DAMS

Seismic Criteria

USBR has a design standard, now in general use, entitled "Seismic Design and Analysis," which is applicable to the seismic design and analysis of embankment dams constructed or evaluated by USBR. The design standard contains guidelines for selection of ground-motion parameters, methods of analysis, seismic design for new dams, seismic response of existing dams, and examples of seismic analysis. Recommended procedures for performing liquefaction analyses, deformation analyses, and considerations for selecting soil strengths for deformation analyses are discussed in the design standard. After a year of use on a restricted basis, it is now being applied in final form.

Hazard Related Studies - Seismic Analysis

Within USBR, a major program is ongoing to evaluate the safety of existing dams and foundations of new dams in highly seismic areas. Dams or dam foundations that are suspected of being liquefiable are evaluated using *in-situ* field testing. SPTs (standard penetration tests) are the primary evaluative tool used. CPTs (cone penetration tests) are used for correlation with SPT work and to expand the area of investigation. SPT values obtained are compared to values established or required according to procedures using empirical data suggested by H. Bolton Seed (and others). In addition, new techniques in determining *in-situ* void ratio and the steady-state of deformation published by Professors Castro and Poulos are currently being established as state-of-the-art quantitative liquefaction evaluation methods within USBR.

Analysis methods to determine seismically induced displacement of the crest of dams have been developed. Three methods—the Makdisi-Seed Simplified method, Newmark rigid mass, and finite-element procedures are available. In the latter two methods, the excess pore pressure due to cyclic loading may be used in the analysis.

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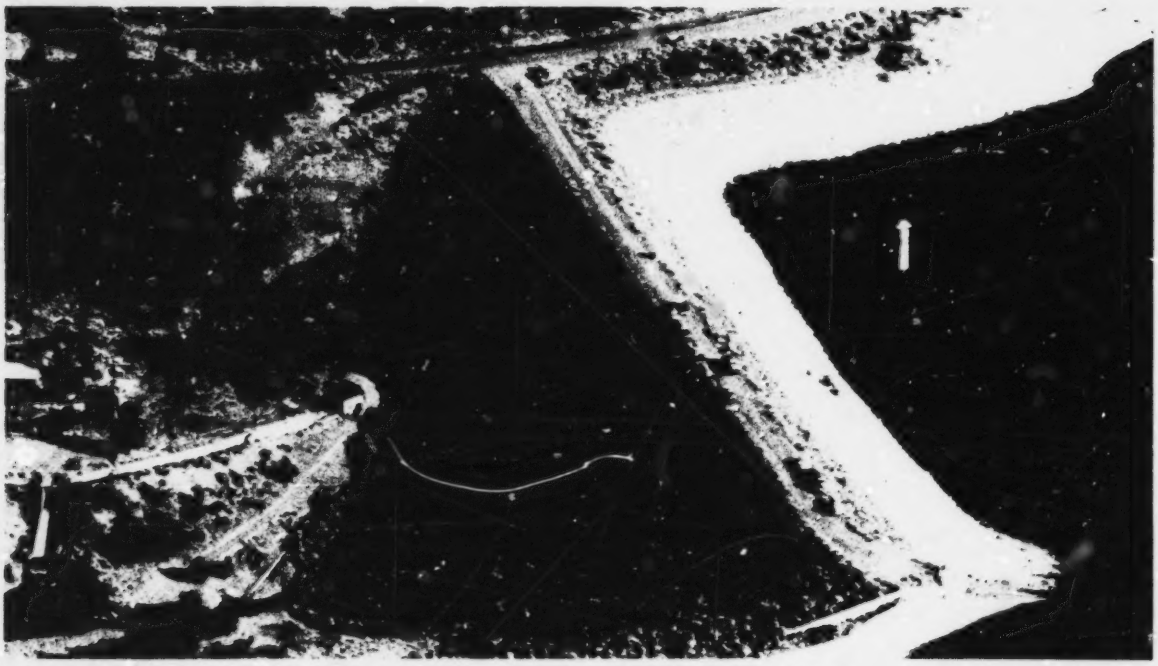

USBR investigations for liquefiable materials in the foundation and embankment of Ochoco Dam located near Prineville, Oregon. The photograph shows equipment used in the drilling program underway on the crest of the dam.

The response of embankment dams to seismic loads is estimated at USBR using a modification to the one-dimensional wave propagation computer program SHAKE. This modification, SHAKEM, allows the program to estimate two-dimensional effects by enforcing shear force compatibility instead of shear stress compatibility at the interfaces between the layers. This is accomplished by multiplying the wave interfaces between the layers. This is accomplished by multiplying the wave equation for each layer by L_i/L_b where L_i is the width of individual layer i, and L_b is the width of the layer representing the base of the dam. The comparisons of computed and observed responses performed to date have been in reasonable agreement, and the SHAKEM program has been used by USBR to compute the dynamic response of several embankment dams.

Risk-Based Analysis for Seismic Design

The USBR has employed a risk-based approach to the analysis of existing dams with regard to their performance during earthquakes. In addition to determining the consequences of dam failure due to an earthquake of a given magnitude, an estimate is made of the likelihood of dam failure given the event. Both liquefaction and nonliquefaction related failures may be examined this way.

The risk-based approach is particularly useful in situations where on-site conditions are not well defined and worst-case assumptions are initially made. If the probability of dam failure can be shown to be sufficiently remote, and the consequences of failure sufficiently insignificant, a detailed and costly investigation program to determine *in-situ* foundation conditions may be avoided. Another concept in the early stages of development is the setting of priorities regarding dam safety problems based on hazard assessment using a risk-based approach.

Examples of Seismic Dam Design and Analysis

San Justo Dam, recently constructed near

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Hollister, California, between the Calaveras and San Andreas fault, is located in one of the most seismically active areas in the world. State-of-the-art analyses were performed throughout the design of this earth embankment to determine the dynamic stability of this structure. A liquefaction analysis was performed using the steady-state of deformation procedures as described by Professors Castro and Poulos. Laboratory tests were performed to develop steady-state lines for two soils used in the embankment and one foundation sand unit. The foundation unit was shown to be nonliquefiable, and for the embankment sands, minimum densities were specified which will prevent liquefaction of these units. Seismically induced deformations were estimated using a detailed, computerized application of the Newmark procedure and also by a finite element strain potential method.

Jackson Lake Dam, located in Grand Teton National Park, Wyoming, was constructed between 1910 and 1916 to enlarge an existing natural lake. Studies have determined that the earthen embankment and large portions of the foundation are susceptible to failure by liquefaction in the event of moderate ground shaking from either local or distant earthquakes. A detailed site-specific seismotectonic study concluded that there were several seismically active faults in the vicinity with the most significant being the Teton fault, which is capable of generating a magnitude 7.5 earthquake at an epicentral distance of 12 kilometers. Several alternatives were examined to eliminate the clearly established hazard to people and property downstream. Alternatives considered included modifying the existing Jackson Lake Dam, restricting reservoir level to a lower elevation, constructing a new dam at a different site, and returning to the natural lake level. The alternative recommended was to modify the existing dam by placing compaction piles to densify the foundation and to replace and enlarge the embankment.

Oblique aerial view of San Justo Dam under construction. View is from downstream and shows embankment plus a portion of the reservoir site beyond. San Justo Dam is located near Hollister, California and is 2.0 kilometers northeast of the San Andreas fault.

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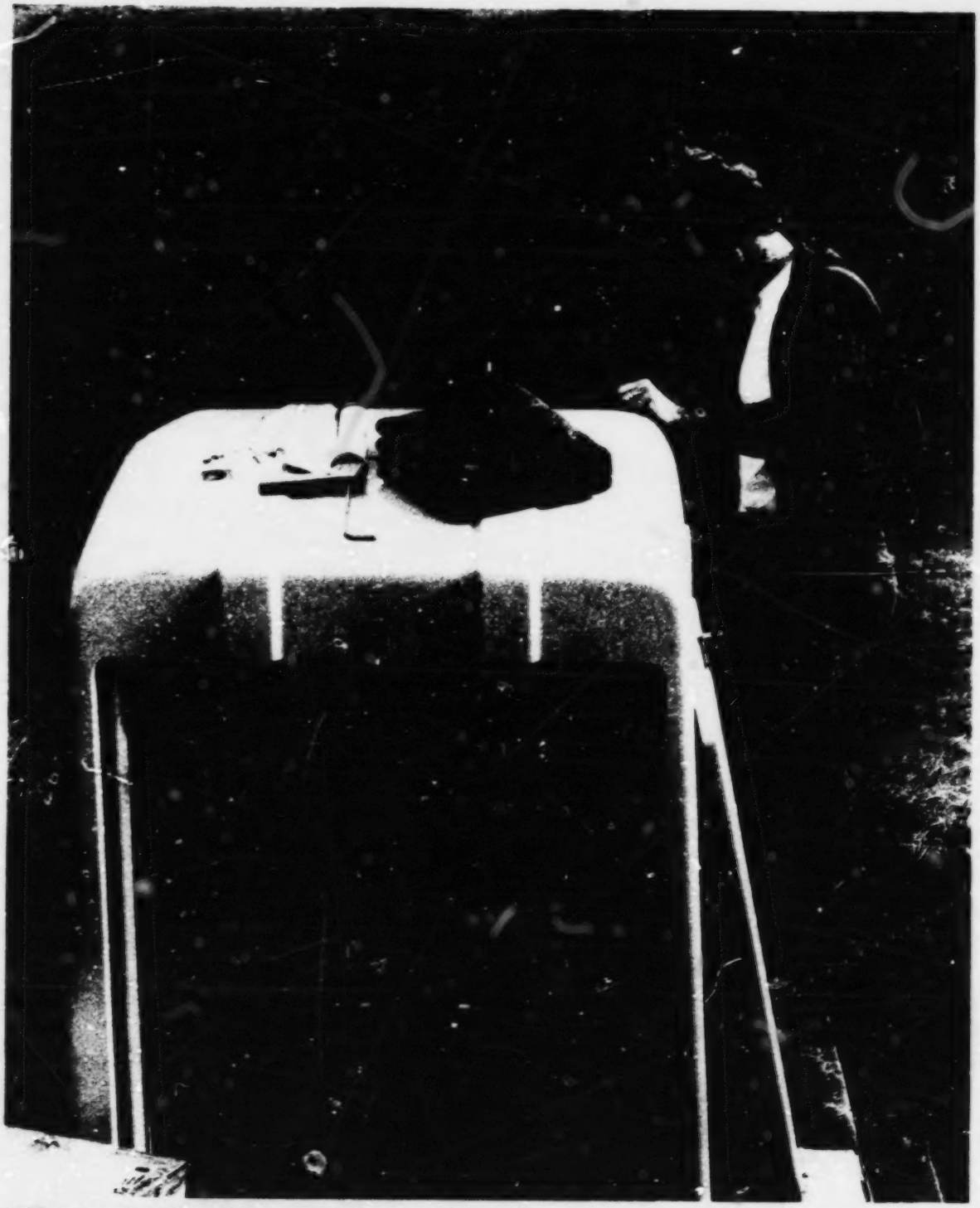

USBR strong motion instrument and housing installation on the crest of Scoggins Dam near Portland, Oregon. Photograph is facing downstream in Scoggins Creek Valley.

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USBR SEISMIC DAM DESIGN AND ANALYSIS — CONCRETE DAMS

USBR is progressing in a program to examine the nonlinear behavior of a dam, foundation, and reservoir system subjected to seismic loading. A first step in this program was accomplished with a finite element structural analysis of a double curvature thin arch dam which models the nonlinear behavior of the vertical contraction joints.

In order to perform this analysis, the "curved isoparametric interface surface element" described in a technical note by Buragohain and Shah was coded and installed in the 1978 version of ADINA. The element proved to be effective when a sufficiently fine mesh is used and when an appropriate integration order is used in the isoparametric element.

The nonlinear no tension contraction joint analysis was compared with an identical arch dam model differing only in its ability to transmit tension across its contraction joints. This comparison allowed the isolation of the nonlinear effect of the joint opening. The inclusion of the nonlinear joints in the analysis was clearly effective in reducing the calculated tensile arch stresses on the upstream face.

STRONG MOTION INSTRUMENTATION PROGRAM

Strong motion earthquake instruments are deployed in selected dams, bridges, and other lifeline structures in areas of high seismic activity in anticipation of large ground motions from nearby earthquakes. These instruments measure the response of the structure due to earthquake loading. These strong motion instruments are seismograph-type systems consisting of accelerographs that remain passive until activated by strong ground motion and then record the acceleration/time history measuring the response of the structure.

The USBR has installed earthquake strong motion instrumentation systems at many of its projects containing critical structures. The purpose of USBR's strong motion instrumentation system program is to obtain data on the nature of strong ground motion resulting from earthquakes in order to evaluate the performance of critical structures subjected to earthquake loading; and to provide a basis for the evaluation of the results of dynamic analysis as well as for improved design of those structures located in seismically active areas. This is accomplished by examination and comparison of acceleration time histories as recorded by various strong motion systems located in critical areas of structures and in foundations.

During Fiscal Year 1986, strong motion instruments were deployed at seven dams in the States of Arizona, Utah, Idaho, and Montana. The program realized many modifications during this fiscal year as numerous instruments have been relocated to improve their input motion/response motion characteristics and thus produce strong motion data that will optimize dynamic analyses following major earthquakes. At the end of Fiscal Year 1986, USBR had 40 dams, damsites, or major project features containing strong motion instrumentation. Fifteen of the 35 sites are in California and nine are in Utah.

RESEARCH

In addition to the activities previously described, USBR conducts research related to earthquake effects on materials and structures. Projects underway in Fiscal Year 1986 included dynamic properties of concrete, engineering properties of rockfill materials, behavior of concrete dams during extreme seismic events, and dam safety instrumentation.

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DEPARTMENT OF DEFENSE

The Fiscal Year 1986 activities of the Department of Defense (DoD) contributed significantly to the implementation of the National Earthquake Hazards Reduction Program in the areas of improved seismic design criteria and guidelines, research, investigation and studies, seismic instrumentation, education, and coordination.

IMPROVED SEISMIC DESIGN AND GUIDELINES

The DoD continued to develop and implement improved seismic design criteria and guidelines for buildings and dam structures. These improved criteria were developed by utilizing the latest state-of-the-art concepts and the recent experience and data obtained from past performance of structures subjected to major earthquakes. DoD has essentially taken the lead among federal agencies in the implementation of improved seismic design criteria and guidelines for seismic resistant structures.

Military Construction

New improved seismic design criteria and guidelines for military buildings being developed and implemented are as follows:

Seismic Design Guidelines for New Essential Buildings, TM 5-809-10-1/NAVFAC P-355.1/AFM 88-3, Chapter 13, Section A, was published in 1986. Two levels of seismic ground motions are used for dynamic analysis in this manual. For the first level, buildings will be designed to remain elastic so that the damage control for a moderate earthquake is maintained. For the second level, buildings will be designed for inelastic behavior based upon limited ductility ratios so that the main functional operation is maintained after a major earthquake. Also, the specification to develop the site-dependent ground motions is provided. A 5-step procedure is prescribed. For areas with certain soil profiles, epicentral distances, and magnitude conditions, the ATC 3-06 data and provisions are used to determine the site-dependent earthquakes. Separate procedures are provided for the eastern and western United States.

Seismic Design Guidelines for Upgrading Existing Facilities, TM 5-809-10-2/NAVFAC P-355.2/AFM 88-3, Chapter 13, Section B, is being developed and will be completed in 1986. This manual encompasses the procedures and requirements for building inventory reduction of military installations, preliminary screening and prioritizing, preliminary evaluation, detailed structural analysis, development of design concepts for seismic upgrading, cost and benefit analysis, final design documents, and upgrading of nonstructural elements. The methodology utilizes the two seismic ground motions as required for new structures. The Navy's "Rapid Seismic Analysis Procedure" software computer program is described for use. Also, an alternative method for upgrading existing buildings in accordance with modified static-code provisions is prescribed. The upgrading requirments in this manual are based upon the design experiences of past upgrading projects within the DoD and the latest state-of-the-art concepts.

The seismic design manual, *Seismic Design for Buildings*, TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13, dated February 1982, is currently available from DoD agencies.

Civil Works Construction

The Corps of Engineers (CE) has continued to develop and implement criteria and requirements for earthquake analysis and design of civil works structures.

Earthquake Analysis and Design of Concrete Gravity Dams, ETL 1110-2-303, was completed in 1985. This Engineer Technical Letter (ETL) contains criteria and guidance for assessing the seismic resistance of new and existing concrete gravity dams. The structural analysis for earthquake loading is in 2 parts: (1) the traditional overturning and sliding stability analysis using an appropriate seismic coefficient, and (2) a dynamic internal stress analysis using the site-dependent earthquake ground motions. In both cases, the selected pool level will be judged at the level most likely to exist coincident with the selected design seismic event. This means the pool level which occurs on the average on a relative frequency during the year.

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Structural Design and Analysis of Intake Towers, EM 1110-2-XXXX, will be completed in 1986. This Engineering Manual (EM) will contain 11 chapters and three appendices which will include a discussion on past experiences with intake towers' response during earthquakes and available methods to evaluate the *in-situ* dynamic properties of existing towers with vibration tests; the description of specifying earthquake ground motion, dynamic models, dynamic analysis methods, a seismic reinforced concrete design, overturning and sliding stability, the evaluation of analytical results, defensive design measures, the effect of appurtenant structures on the response of intake towers; and a reference for the seismic design of the appurtenances. Also, comparisons of examples of analyses and the ATC 3-06 method will be provided.

Engineer Technical Letters (ETL) currently prepared to establish requirements and procedures are: (1) *Analyzing the Seismic Stability of Embankments and Foundations;* and (2) *Site Investigations for Seismic Stability Studies of Embankments and Foundations.*

Seismic design publications currently available are: (1) ETL 1110-2-301, *Interim Procedure for Specifying Earthquake Ground Motions*, dated 26 September 1983; (2) Engineering Regulation, ER 1110-2-1806, *Earthquake Design and Analysis for Corps of Engineers Dams*, dated 30 April 1977.

Improved Criteria Implementation

DoD has implemented dynamic analysis design concepts with site seismicity studies for several hospital designs.

The earthquake resistant design of all new Navy hospitals is being based upon site seismicity studies and dynamic analysis. These include the hospitals at Bremerton, WA (completed in 1980); at San Diego, CA (under construction); at Philadelphia, PA (economic study underway); and the new hospital to be located at Subic Bay, Republic of the Phillipines (design underway). These techniques were also used for the major seismic upgrading of the existing hospital at Oakland, CA. The Oakland project involved additions (buttress type) at the ends of the four 9-story wings which were tied into the existing structure. A somewhat unusual design concept was adopted which relies on the new steel frame additions to gradually pick up the lateral load as the original reinforced concrete structure goes into inelastic behavior under the very large earthquake motions. Modifications included improvements to utilities and nonstructural elements. The project intent is to have the hospital survive a large earthquake and enhance its likelihood of remaining functional after a moderate seismic event.

The design of the new Air Force hospital at Travis AFB, CA, utilized the site-specific seismic ground motions and dynamic analysis concept. The construction contract for this project was awarded in June 1985.

The CE has applied the dynamic analysis approach for seismic design to several hospitals. These include Fort Campbell, KY (completed 1982); Fort Knox, KY (completed in 1981); Letterman Army Medical Center, Presidio of San Francisco, CA (completed feasibility studies only); and Madigan Army Medical Center, Fort Lewis, WA (under construction).

RESEARCH

DoD agencies have continued actively in research for seismic design and requirements for direct application in projects.

The U.S. Army Engineer Waterways Experiment Station (WES) is continuing to improve procedures to evaluate the liquefaction of gravels. WES is assisting in development of field measurement of cyclic strength of gravels with Becker Hammer Drilling equipment, and has developed a large data bank of laboratory determined cyclic strengths for corroboration and extrapolation of *in-situ* results. Also, WES is developing software to accompany a statistical procedure for monitoring compaction data during earthquake construction.

WES initiated, in 1985, a research program with the objective of validating a new method for evaluation of seismic stability of dams. In

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this effort, the Lower San Fernando Dam, which suffered a massive slide in its upstream shell during the San Fernando Earthquake of 1971, has been re-explored during Fiscal Year 1986 with soil borings, penetration tests, and the excavation of a shaft for testing of samples. An analysis of the dam's seismic stability is also underway. The results of tests and analysis will be compared with the observed performance during the 1971 earthquake.

WES is managing a cooperative research effort with the University of British Columbia and Cambridge University to study seismically induced settlements in soil, using the geotechnical centrifuge. This effort is co-sponsored by the U.S. Nuclear Regulatory Commission. The goal of this effort is to be a methodology for two-dimensional, nonlinear, soil-structure interactive, dynamic effective stress analysis.

Under the Corps of Engineers (CE) REMR program, WES is investigating and studying techniques and methodology for the remedial treatment of liquefiable foundation beneath existing structures. A first report on this effort has been published and two more are in progress.

A civil works study entitled "Earthquake Hazard Evaluations for Engineering Sites" is:

- Evaluating factors such as age of deposits, sedimentation and geomorphic processes, seismic history, weathering, ground water, slopes, cementation, etc., for effects on susceptibility to liquefaction.
- Specifying components of ground motion (frequency, equivalent cycles, power densities, etc.) for earthquake assessments at engineering sites.
- Characterizing parameters of earthquake ground motions, seismic source zones, and criteria for recurrence.
- Developing methods for selecting optimum analogous records for earthquake ground zones and for specific geological-seismological conditions at a site.

The Air Force continued to conduct research within:

- The area of geodesy and gravity, on the fundamental earth properties to derive geodetic and astronomic positions, to determine and improve the shape of the geoid, and to model the acceleration of gravity. Improved instrumentation has been developed to measure various geodetic parameters with increased precision. Interferometric techniques are being developed which could greatly improve measuring geodetic baselines. Studies continue to obtain information about the small-scale variations of the geoid using analyses of satellite orbits. These programs are directed toward meeting the goals of the geodetic and gravimetric contributions to future Intercontinental Ballistic Missile (ICBM) and cruise missile error budgets.
- The area of earth motions to measure and characterize the effects of motions (natural, cultural, and those due to nuclear detonation), on various systems, e.g., missiles and launch vehicles. Models of ground motions, due to nuclear detonations, are based on measurements of the propagation of seismic waves associated with earthquakes and controlled detonation of chemical explosives. Various analytic, laboratory, and empirical models will be compared to verify predictions of ground motions at likely basing sites for advanced ICBMs. The experience gained from modeling seismic propagation in complex terrain is being used to predict the seismic and acoustic loads on various buildings during Space Transportation System launches.

INVESTIGATION AND STUDIES

DoD agencies continued to assess existing military facilities in terms of seismic hazards and to upgrade seismically deficient buildings. Also, CE has continued to assess civil works structures for the dam safety program. Several projects have been completed on the assessment of seismic hazards to existing facilities.

WES was involved with, or has completed, several safety study projects in 1986 for various Corps of Engineers (CE) Districts, specifically Wappapello Dam (Missouri), Arkabutla Dam (Arkansas), Barkley Dam (Kentucky), Folsom Dam (California), and Ririe Dam (Idaho). By way of interagency coordination it should be noted that the U.S. Bureau of Reclamation (USBR) operates the Folsom and Ririe projects.

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The Naval Facilities Engineering Command (NAVFAC) continued investigations of major bases located in seismic zones 3 and 4. Work was completed on approximately seven bases bringing the total bases completed to 59 out of 99. The studies include determination of seismicity, evaluation of site hazards, preliminary evaluation of utilities, and evaluation of structures. Where remedial measures are found, necessary costs and project documentation are provided. Also, design case studies were initiated for the use of base isolation compared to conventional design. These included applications to existing structures.

The Naval Civil Engineering Laboratory (NCEL) initiated studies of requirements for further evaluation and improvement of utility systems. This effort includes the use of computer mapping and bases. Also, continued investigations of earthquake analyses for dry docks are being made. Tests to establish damping values of cranes were completed. The results will be incorporated into crane specifications.

The U.S. Army Construction Engineering Research Laboratory (CERL) completed the detailed structural analyses to seismically upgrade two existing buildings at Fort Ord, CA. A telephone exchange building and an aircraft maintenance building were selected from a prioritized list of seven buildings. These prioritized buildings were established as a result of a screening and preliminary evaluation process of more than 3,600 buildings on the base. These two buildings will be upgraded to maintain their operational functions after a major earthquake.

SEISMIC INSTRUMENTATION PROGRAM

DoD agencies have continued to monitor and provide additional strong motion seismic monitoring systems.

Military Construction

The CE continued to install strong motion seismic monitoring systems in hospitals. Currently, three Army hospitals have strong motion instruments. Seismic instruments will be installed in the new $300M Madigan Army Medical Center, Fort Lewis, WA, which is under construction.

NCEL continued the program of instrumentation for dry docks. This program will provide recording and analyzing earthquake motions felt at dry docks, determination of the actual periods using ambient vibration measurements, and deflections through a filling and dewatering cycle.

All new Navy hospitals in earthquake zones 3 and 4 include strong motion accelerographs at three or more locations, including a free field instrument. NCEL continued a strong motion instrumentation for naval facilities in selected locations and there are now 23 buildings and 9 drydocks that are instrumented. Free field instruments are located near the instrumented structures. NCEL also installed strong motion accelerographs and ambient vibration detection equipment in Navy structures at Naples, Italy, where swarms of volcanic tremors have caused damage. NAVFAC is having NCEL monitor the period of these structures to determine if structural damage is accumulating.

Civil Works Construction

The CE continues operation of its strong-motion monitoring system for civil works structures and dams. As of May 31, 1986, the CE had installed 400 accelerographs, 14 seismic alarm devices, 56 seismoscopes, and 34 peak recording accelerographs at 119 projects located in 34 States and the Commonwealth of Puerto Rico. Forty-five more accelerographs are planned for future-year installation. An earthquake record from the Ohio Earthquake of January 31, 1986 (magnitude 5.0), was obtained from the crest of the Michael J. Kirwan Dam. Longitudinal, vertical, and transverse components of acceleration were measured. These data are the first strong-motion information recorded in Ohio. Recently, 10 strong-motion records from the Palm Springs Earthquake of July 8, 1986, southern California, were retrieved from the following sources: 3 records each from instruments at Brea Dam and Prado Dam and 2 records each from Carbon Canyon Dam and San Antonio Dam. These

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records have not yet been analyzed by WES. The final report on "Earthquake Response Spectral Analysis of Franklin Falls Dam, New Hampshire," by F. K. Chang, was published by WES in Fiscal Year 1986.

An Engineer Circular, EC 1110-2-511, *Static Report on OCE Strong-motion Instrumentations Program for Measurement of Earthquake Motions* is published annually.

EDUCATION PROGRAM

The CE continued to sponsor the annual 5-day training course on "Seismic Design for Buildings" which utilizes the 1982 edition of the Tri-Services Manual, TM 5-809-10/NAVFAC P-355/AFM 88-3, Chapter 13, *Seismic Design for Buildings.*

In June 1986, WES provided a 1-week training program on seismic safety evaluation of large earth dam and reservoir projects for a visiting Fulbright Scholar, Dr. Kyriacos Kyron, of Cyprus. A 1-year training and research program in earthquake engineering is being provided during Fiscal Year 1986 and Fiscal Year 1987 for Mr. Takashi Tsuchida, an engineer of the Japanese Port and Harbour Research Institute.

COORDINATION ACTIVITIES

DoD continued to participate in the activities of the Interagency Committee on Seismic Safety in Construction (ICSSC). Army, Air Force, and Navy representatives participated in the ICSSC subcommittees. Also, DoD components are represented in the Building Seismic Safety Council (BSSC) work.

WES participated in the American Society of Civil Engineers committees on scil dynamics, soil properties, geotechnical safety, and reliability.

NAVFAC participated in the activities of the National Research Council (NRC) Committee on Earthquake Engineering including contributions to a state-of-the-art report on liquefaction with support funding.

The CE participated in and contributed to the development of National Research Council publication, *Safety of Dams, Flood and Earthquakes Criteria.* The NRC established an ad hoc committee on safety criteria for dams to prepare an inventory of currently used criteria for dams relating to safety from hazards of extreme floods and earthquakes which resulted in this publication.

On an international level, CE—including WES and NAVFAC—participated on the Joint U.S. and Japan Panel on Wind and Seismic Effort which held its annual meeting in May 1986 at NBS to exchange the latest information and data on seismic research and studies. In July 1986, WES co-sponsored with Cambridge University, an international symposium on geotechnical centrifuge dynamic modeling of test data and earthquake hazard mitigation.

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DEPARTMENT OF ENERGY

POLICY

The Department of Energy (DOE) continues to strengthen the awareness and broaden the involvement of its program offices and field organizations in the activities of the National Earthquake Hazards Reduction Program (NEHRP). The following major organizational units of the DOE are involved in natural phenomena hazard mitigation programs which include the activities of the NEHRP:

- Management and Administration
- Defense Programs
- Energy Research
- Environment, Safety and Health
- Fossil Energy
- International Affairs and Energy Emergencies
- Nuclear Energy
- Civilian Radioactive Waste Management
- Power Marketing Administrations

These organizations are responsible for implementing requirements of Departmental Orders, including specified consensus standards (i.e., seismic requirements of the *Uniform Building Code* and the *Seismic Design Guidelines for Federal Agencies*). The Assistant Secretary for Environment, Safety and Health (ES&H) has responsibility for providing an independent review to ensure acceptable achievement of safety by the program organizations.

The 1985 Department of Energy section in the *Report to Congress* highlighted a comprehensive hazard mitigation policy, implementation of that policy, seismic technology development, development of codes, standards and guidance, and the commitment of DOE to the NEHRP. The following presents activities in the above areas for 1986, and reports on the Secretary of Energy's initiatives to strengthen the Environment, Safety, and Health program. Details of the DOE Natural Phenomena Hazards Mitigation Conference and evaluations and upgrading at specific facilities are also presented.

EARTHQUAKE HAZARD MITIGATION

Headquarters Initiatives

On September 18, 1985, Secretary of Energy, John S. Herrington, announced a restructuring of the Department's Environmental, Safety and Health program that features centralized and upgraded controls, a comprehensive environmental survey, and special safety appraisals of DOE nuclear facilities.

A series of actions were ordered to strengthen the Environment, Safety and Health program within DOE. This multi-faceted plan contains three principal elements.

First, oversight responsibility for the environment, safety and health function in the Department will be consolidated and upgraded under the direction of an Assistant Secretary for Environment, Safety and Health. Formerly, oversight responsibility for environment and safety was scattered among the program Assistant Secretaries.

Secretary Herrington stated:

"Consolidating this function under a strong Assistant Secretary will establish line responsibility and top-management commitment to safety and environment. ES&H will be stronger and better organized. It will have more oversight tools and it will be integrally involved in the operations of the Department at all levels."

This has also enhanced the DOE natural phenomena hazards mitigation program since it is managed within the ES&H structure at Headquarters.

The second part of the plan involves a thorough environmental survey of all DOE facilities to identify problem areas and rank them in order of priority. Five teams began their review and preliminary sampling and analysis this year. Data from the survey will be used to develop a methodical approach to assigning priorities to ES&H concerns and working for their resolution.

The third facet of the ES&H upgrading is Technical Safety Appraisals of DOE nuclear

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facilities. Herrington said that these appraisals will look at compliance with safety requirements in the Department's nuclear facilities. The appraisals will take into account the safety lessons learned in private industry as well as licensed facility requirements. The Technical Safety Appraisals begin in March 1986. Over 50 nuclear facilities will be appraised during a 3-year period.

The above initiatives have strengthened the DOE earthquake hazard mitigation program. Additional resources were provided during Fiscal Year 1986 to accomplish facility design reviews, peer reviews of earthquake mitigation projects, and evaluation of safety analysis reports for natural phenomena hazard considerations.

The Technical Safety Appraisals include review of earthquake emergency preparedness and other seismic considerations. A recent Design Review of the N Reactor at the Hanford Site near Richland, Washington, included experts in seismic hazard mitigation. Recently developed seismic criteria were used to evaluate the reactor facility.

Chicago Operations Office

Argonne National Laboratory-West (ANL-W)

ANL-W is located on the Snake River Plain in southeastern Idaho. Historically there has been little seismic activity on the plain itself; however, there has been significant recent activity (Hebgen Lake Earthquake, 1959; and Mount Borah Earthquake, 1983) in the surrounding mountain ranges. Hence there is and has been a concern and a need to assure the safety of reactor and other nuclear facilities at ANL-W.

At ANL-W, most of the reactors and fuel reprocessing/fabrication structures were designed and constructed prior to the implementation of the recent, aggressive DOE seismic standards. Despite the lack of DOE seismic criteria (at the time of the design), ANL-W typically adopted a more aggressive posture regarding seismic safeguards than was then required. This safety posture was reflected in design of the seismic shutdown systems rather than in structural design of the reactors and other nuclear facilities. With the systematic increased interest and concern for seismic safeguards, the existing seismic scram systems have subsequently been reviewed and upgraded as deemed prudent. Structures and reactors designed in the 1950s and 1960s have been and are being analyzed to determine their structural resistance in a seismic event.

All of the major reactors at ANL-W have received attention from a seismic standpoint. The three major reactors are the Experimental Breeder Reactor-II (EBR-II), the Zero Power Plutonium Reactor (ZPPR), and the Transient Reactor Test Facility (TREAT).

EBR-II was designed in the late 1950s and constructed in the early 1960s. At the time, there were no specific seismic design guidelines so the Uniform Building Code (UBC) (or equivalent static analyses) was used in the design. To assure that EBR-II would not experience a criticality problem during a seismic event, a seismic scram system was included in the original plant protection system and remains in use. This system has field sensors which detect ground motion and provide signals which would lead to a reactor scram if the trip point is exceeded. The system is set to trip for any ground acceleration (horizontal or vertical) in excess of 0.005 g. In 1977, a dynamic seismic analysis was performed to analyze the EBR-II primary tank system and other selected components. In 1983, further dynamic analysis was done to assess the structural integrity of the primary tank system following the Mt. Borah Earthquake. This analysis showed that the primary tank support hangers (the most vulnerable components) were not seismically challenged and could have safely experienced g-loadings of about 4 times those caused at EBR-II by the Mt. Borah Earthquake.

Both the TREAT and ZPPR reactors were designed using UBC/equivalent-static type analyses. ZPPR was designed with only a horizontal ground motion detector which would provide a scram signal during a seismic event. In 1981, the ZPPR seismic detection system was upgraded with dual seismic triggers capable of detecting both horizontal and vertical motions, as well as providing a scram signal for any ground acceleration in excess of 0.01 g. In its

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original design, TREAT was not provided with a seismic detection/scram system. A new plant protection system is planned to be installed in TREAT during November 1986, and this will include a seismic sensor/scram capability. TREAT has been analyzed using dynamic models. Results from this analysis have led to the replacement of some of the hardware in the control rod drive support columns.

With the exception of the Fuel Manufacturing Facility (FMF), which has been designed and constructed to meet current seismic standards, all of the fuel reprocessing facilities are relatively old and hence were designed using UBC/static type analyses. In addition, the proposed use and refurbishment of the Hot Fuel Examination Facility (HFEF/S) for plutonium processing for the Integral Fast Reactor(IFR) program has led to the need for dynamic analyses of that existing structure. These analyses are now being done using the latest DOE seismic guidelines. Preliminary work indicates that HFEF/S will meet DOE criteria although this structure was designed over 20 years ago using the UBC. The FMF was designed in 1985 and constructed in 1986 using seismic criteria which are much more aggressive than those presently recommended by DOE.

In general, ANL-W has met or exceeded the seismic standards in force at the time a particular reactor or nuclear facility design was initiated. As the seismic design criteria have become more stringent, some of the reactors and other nuclear facilities cannot meet these new standards. With these older reactors and other facilities, work has been and is being expended to make them a seismically secure as is reasonably practicable. In particular, dynamic analyses are being performed to assess their vulnerability to seismic events; structural changes have been and are being considered and have been incorporated (where practicable) or will be included; and, seismic scram systems are being upgraded or added to the plant protection system of the major reactor facilities at ANL-W.

Brookhaven National Laboratory (BNL)

In an ongoing seismic upgrading program for the High Flux Beam Reactor (HFBR), that was designed and constructed in the early 1960s by BNL (which is located about 60 miles east of New York City on Long Island, New York), the following seismically related actions have been completed during Fiscal Year 1986 and previous years.

As a part of a previous project to increase the reactor power level from 40 MW to 60 MW, an assessment was performed with respect to current seismic design criteria to determine that a safe reactor shutdown would occur following an earthquake. This assessment identified a number of areas where corrective action was required. Technical upgrading actions, which in most cases involved adding supports for piping and other structures, were developed and implemented. Where the installation of supports was not feasible, a seismically qualified backup system was installed. In addition, the currently applicable seismic criteria have been incorporated in the design requirements for modifications to this reactor facility.

Furthermore, the following measures are currently being developed for use at HFBR. A seismic alarm system is being installed at HFBR which will serve the purpose of promptly alerting the reactor operating staff if an earthquake of potentially hazardous intensity were to occur at the BNL site. This alerting action together with the implementation of written procedures (if the preestablished conditions are exceeded) would then result in a manual scram of the reactor, initiation of certain emergency procedures, and the subsequent performance of a plant damage inspection before restart. Also, as a part of this ongoing upgrading project, triaxial seismic recorders will also be installed to provide a record of the magnitude as a function of time of an earthquake.

Savannah River Operations Office

To determine if upgrading is required, the Savannah River Plant is directly surveying all service type buildings which were built to the Standard Building Code without earthquake provisions. Present standards require design to conform to the Uniform Building Code for seismic design on service type buildings at SRP. The survey will be completed by the end of

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1986. The preliminary survey results may indicate a need for detailed evaluation of some of the buildings.

Work was completed on development of a site-wide wind and tornado hazard model. The evaluation utilized the DOE-wide hazard models developed by the Lawrence Livermore Laboratory for the Office of Nuclear Safety. A corresponding seismic hazard investigation to update the Savannah River Plant seismic design criteria was reported in the DOE activity report for Fiscal Year 1984.

Albuquerque Operations Office

Work is continuing at Rocky Flats Plant, Golden, Colorado, and is being completed at the Sandia National Laboratory, Livermore, California. These line item projects include upgrading and restoration and are funded at nearly $12 million. The Rocky Flats Plant proposed upgrade was given a "peer" review of the earthquake design. This review cost very little but is reported to save the project millions in construction costs.

Oak Ridge Operations Office

Dr. W. J. Hall, University of Illinois, conducted a seismic evaluation of the High Flux Isotone Reactor (HFIR) for the Oak Ridge National Laboratory (ORNL).

The Oak Ridge Research Reactor (ORR) is presntly undergoing an ORNL seismic review. Additionally, a review team from EG&G Idaho has just completed an independent review with respect to the effects of earthquakes. Their findings indicate that the facility may incur damage as a result of a major seismic event; however, the possibility of a nuclear accident resulting from such an event is judged to be very low. Some minor reactor modifications have been made to further reduce the risk.

At the Paducah Gaseous Diffusion Plant in Kentucky, a $4 million retrofit project is planned to modify certain expansion joints in the piping system to improve seismic resistance, thus reducing the potential for UF6 release and plant damage resulting from a potential major earthquake.

San Francisco Operations Office

New line item proposals have been recommended for slope stabilization and structure restoration and upgrading at the Lawrence Berkeley Laboratory and at the Lawrence Livermore National Laboratory. Proposed upgrading is to meet the intent of the 1985 Uniform Building Code life safety provisions. The actual improvements will be designed to more stringent DOE site standards. Estimated cost for the 5-story office building is $6.8 million for the slope stabilization.

Office of Safety, Health, and Quality Assurance

The restoration and upgrading line item construction projects proposed by the operations offices and their operating contractors are evaluated by the DOE Environment, Safety and Health Review Process. During 1986 the natural phenomena hazards mitigation included in proposed line item projects was formally incorporated in the review process. This permitted the life safety merits of proposed seismic mitigation to be evaluated and ranked. The end result was the recommendation by the Assistant Secretary for Environment, Safety and Health for inclusion of projects containing major earthquake mitigation potential in the budget.

SEISMIC TECHNOLOGY DEVELOPMENT

Activity during Fiscal Year 1986 in the U.S. Department of Energy's seismic technology program under the Advanced Reactor Technology Support Effort continues to be in four areas: seismic isolation, fluid-structure interaction on reactor internals under seismic loads, core seismic response methods development, and pipe testing under seismic load simulation. In addition, collaboration and interaction with Japan on seismic technology was continued. Accomplishments and activity of note in these areas are:

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Seismic Isolation

In support of DOE's advanced reactor concept studies, Argonne National Laboratory (ANL) is developing methods for and performing analyses of seismic isolation concepts. ANL analyzed the Sodium Advanced Fast Reactor (SAFR) plant with and without isolation systems to compare the responses to seismic events. The models used represent the building, reactor vessel, steam generators, and pumps as lumped-mass stick models. The isolated system was investigated with two isolation frequencies, 0.5 Hz and 0.75 Hz subjected to different earthquake time-histories. For most time-histories, the isolation system with 0.75 Hz frequency yielded smaller displacements of the structure relative to the ground than the 0.5 Hz system. However, for the Hollywood time-history (earthquake of February 9, 1971), relative displacement from the 0.75 Hz system is significantly higher than the 0.5 Hz system. These results indicate the importance of studying the sensitivity of the design to all parameters, including a wide sampling of earthquakes as well as damping, stiffness, and isolation schemes.

Tests have been proposed on scale models of typical advanced reactor plant isolation concepts to be performed at the University of California at Berkeley (Earthquake Engineering Research Center) laboratory or at the Energy Technology Engineering Center (ETEC) seismic test facility. An important licensing issue is to demonstrate safe and reliable operation of the isolation devices during an SSE.

Fluid Structure Interaction

ANL has performed supporting analyses using their FLUSTR (Fluid/Structure) Code on the Advanced Liquid Metal Reactor Concepts. Internal components such as the core barrel, redan, upper internal structure, heat exchangers, pumps, fuel storage basket and cold traps, as well as the reactor vessel and head are modeled. The hydrodynamic effects on loads, frequencies, pressures, and other parameters of the submerged components are obtained during seismic excitation.

Considering the need for additional validation of the FLUSTR computer program, ANL is supporting the Electric Power Research Institute (EPRI) in their collaboration with the Japanese utility research organization, Central Research Institute of Electric Power Industry (CRIEPI). CRIEPI has fabricated a 1/10 scale model of a large pool-type Liquid Metal Reactor and performed sloshing tests on it under seismic simulation. ANL support consisted of consultation on the model design and analysis of the tests using the FLUSTR code. This cooperation is of mutual benefit since ANL obtains the U.S. capability for fluid-structure interaction analysis which would take them at least four years to develop on their own.

To witness the Japanese sloshing tests, Dr. Yao-Wen Chang of ANL traveled to Japan in behalf of EPRI. He also visited other facilities in Japan.

Core Seismic

Activity in this area included further validation and improvement of core structure modeling for the GSCRAP computer code. This code is the General Electric version of the SCRAP code originally developed by ANL. SCRAP stands for Seismic Core Response Analysis Program.

The experimental data for this validation work were obtained from the Earthquake Engineering Research Center (EERC) of the University of California at Berkeley, the Hanford Engineering Development Laboratory (HEDL), and through exchange agreements with Project Nuclear Fuels Corporation (PNC) of Japan. Each of these organizations conducted dynamic tests on core elements.

At the EERC the load pad impact tests were completed. These tests were done to generate parameters for improving the local impact models in GSCRAP and for developing load limits for the assembly load pad seismic design. The EERC data supports the use of static behavior models for the load pad response when performing dynamic structural analysis of the core.

At HEDL, the tests on full-size ducted core assemblies were completed. They provide benchmark data for validating the GSCRAP

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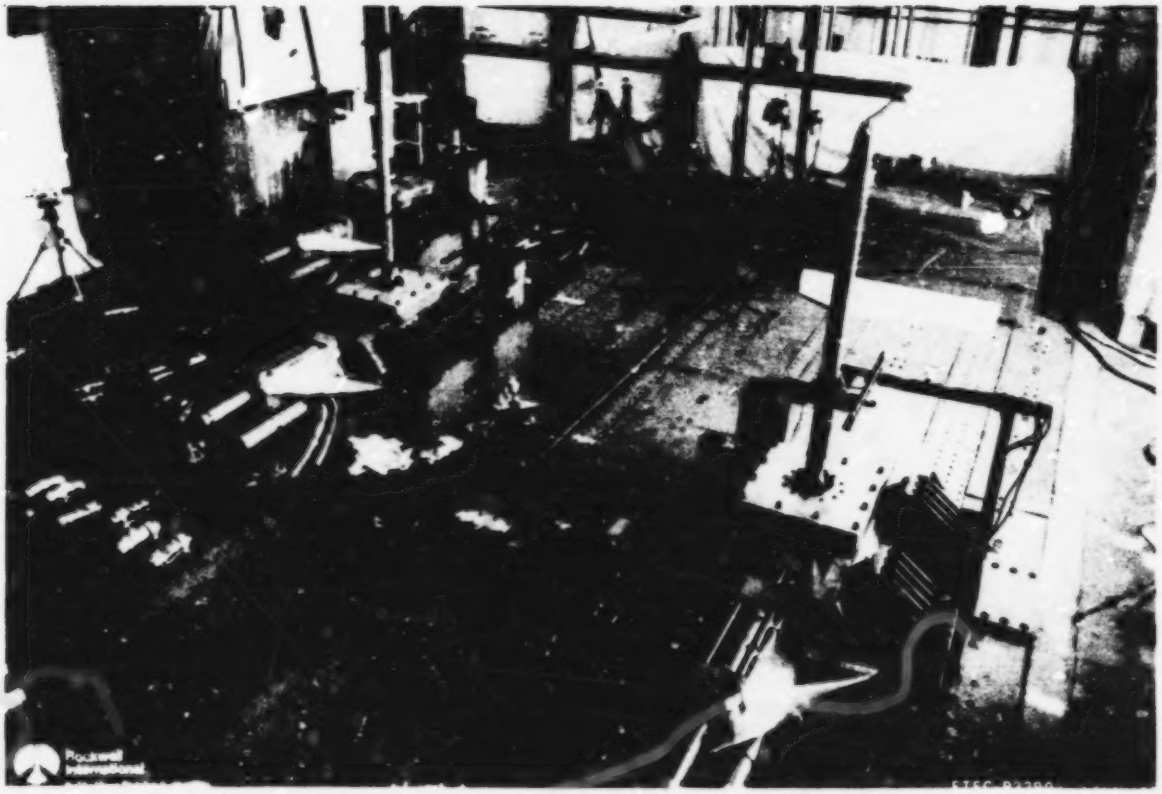

ETEC Seismic Test Facility

Code. Single and five-assembly rows were supported so as to simulate free flowering core boundary conditions that can be important to inherent safety designs. These results are being used by General Electric Company in validation studies on GSCRAP.

Further supplemental test data were obtained from PNC to complete the data base required for effectively using the core test data on vibration tests on core assembly clusters originally obtained from PNC in exchange for SCRAP. These new data were obtained in a DOE-PNC Core Seismic Specialists' meeting held at HEDL. These data plus the HEDL test data complete the data base required for validating GSCRAP.

Pipe Testing

Collaborative tests to failure at ETEC under both DOE and U.S. Nuclear Regulatory Commission sponsorship were completed on 3-inch and 6-inch diameter pressurized piping. Seismic capacities under very high-level excitation revealed large margins above current design allowables. Improved analysis methods development is under way at HEDL to predict the high-level response and failure levels of the piping systems. More reliable and economic pipe and piping support designs will be facilitated by these improved design techniques.

The ETEC facility consists of four shaker pedestals on which the pipe model is mounted. The ETEC facility has the capability to shake a piping system to extremely high accelerations so that actual failures, either collapse or fracture, can be obtained. This provides the unique capability to actually determine design margins to failure, not previously known for piping under seismic loading. Advanced non-linear analysis methods and revised failure criteria can be validated.

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SEISMIC INSTRUMENTATION

The seismic program, operated by USGS for the Nevada Waste Management Project Office, supports a program which consists of over 45 high-gain seismographs deployed on and off the Nevada Test Site. It documents the seismicity of Yucca Mountain and its surroundings. Information obtained through this program is available from the Office of Scientific and Technical Information, Oak Ridge, Tennessee.

The Savannah River Laboratory is expanding and improving the capabilities of the Savannah River Plant (SRP) Seismic Network. This includes the addition of seven vertical and two horizontal seismometers to the present three vertical seismometers in the network. Also, an automatic digital recording and analysis system is to be installed in the observatory to record on tape and analyze the seismic signals recorded to provide information on time of origin, location and magnitude of seismic events. This instrumentation was utilized in evaluating the June 1985 earthquake whose epicenter was located on the SRP, as further described in the report: *Savannah River Plant Earthquake of June 1985 (DPST-85-583).* Also, plant instrumentation results are utilized and reported in the *Southeastern U.S. Seismic Network Semiannual Bulletins* compiled by the Seismological Observatory at Virginia Polytechnic Institute, Blacksburg, Virginia.

Seismic strong motion instrumentation at the Idaho National Engineering Laboratory, the Lawrence Livermore National Laboratory, and the Oak Ridge National Laboratory were reported in the DOE Activity Report for Fiscal Year 1984.

CODES, STANDARDS AND GUIDANCE

Under the auspices of the Department of Energy (DOE) General Design Criteria (GDC) Planning Board and in conjunction with a major contract which was awarded to the American Consulting Engineers Council/Research and Management Foundation (ACEC/RMF), in June 1985, work continues to improve the GDC Manual. This manual includes GDC for the mitigation of earthquake and other natural phenomena hazards, as well as the entire spectrum of GDC required in designing DOE facilities. To date, ACEC/RMF has reformatted the manual into the Construction Specifications Institute (CSI) *MASTERFORMAT*. Additionally, an intensive effort was expended to identify problem areas in the manual which need resolution. DOE Headquarters, field organizations, and private architect-engineering firms participated in that assessment. ACEC/RMF then developed highly focused statements of work for subcontracting expertise. First drafts of the improved GDC manual will be available in September 1986.

The following guidance documents were developed for the Office of Nuclear Safety by the Lawrence Livermore National Laboratory and others for use in earthquake mitigation programs:

- *Design and Evaluation Criteria for DOE Facilities Subjected to Natural Phenomena Hazards* (draft);
- *Suspended Ceilings System Survey* and *Seismic Bracing Recommendations*, UCRL 15714, August 1985; and
- *Practical Equipment Seismic Upgrading and Strengthening Guidelines*, UCRL 14815, November 1985.

TECHNOLOGY TRANSFER

The *Proceedings of the DOE Natural Phenomena Hazards Mitigation Conference* (Conf-8510118) documented the papers presented at the October 7-11, 1985 conference held in Las Vegas, Nevada. Approximately 170 attendees and participants from most major DOE and DOE contractor organizations were represented. In addition, representatives from other agencies and the private sector were on hand. This is reported to be the first conference to cover most natural phenomena hazards and the associated measures for mitigation. The conference included six mini courses taught by experts. These courses were video-taped and are now available as a complete set of tapes and workbooks from the Office of Nuclear Safety's Project Management Organization, Lawrence Livermore National Laboratory. Course titles are:

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- *Seismic Analysis*, R.P. Kennedy and B.A. Short, UCRL-15742, 10/85
- *Seismic Design*, J.P. Nicoletti, L.E. Malik and P.G. Griffin, UCRL-15744, 10/85
- *Emergency Preparedness*, P.I. Yanev et al, UCRL-15746, 10/85
- *Extreme Wind and Tornadoes:* An Overview, J.R. McDonald, UCRL-15745, 10/85
- *Extreme Winds and Tornadoes: Design and Evaluation of Buildings and Structures*, J.R. McDonald, UCRL-15745, 10/85
- *Overview of Flood Considerations*, M.W. McCann, Jr. and H.J. Owen, UCRL-15743, 10/85

The "Third U.S. National Conference on Earthquake Engineering" was supported by DOE. DOE operations offices have accomplished much in defining earthquake hazards in the Eastern U.S. Structures have been built and/or upgraded to meet severe earthquake loadings.

DOE continues to participate actively in the program of the Interagency Committee on Seismic Safety in Construction. During 1985 and 1986, 20 DOE Headquarters and Field Staff, including contractor observers, were appointed to the five subcommittees of the ICSSC. DOE also continued involvement in the National Earthquake Response Plan.

Seismic mitigation and safety of DOE dams were reported and discussed in the biennial report of the Interagency Committee on Dam Safety: *National Dam Safety Program: A Progress Report* (FEMA 103/4/86). The report contains a description of the $20 million cost of mitigating the potential for liquefication of a new dam built by the Corps of Engineers for the DOE near Aiken, South Carolina.

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GENERAL SERVICES ADMINISTRATION

Through the Office of Real Property Development, Public Building Service, the General Services Administration (GSA) continued to support the activities of the National Earthquake Hazards Reduction Program during 1986. GSA's technical representatives serve on the Interagency Committee on Seismic Safety in Construction (ICSSC), and ICSSC subcommittees.

As in previous years, the GSA continued in 1986 to analyze, through private engineering firms, buildings located in high seismic risk areas of the United States and took steps to strengthen buildings to resist earthquake forces as specified by acceptable codes.

GSA is developing a plan to evaluate systematically the entire stock of existing buildings for seismic safety during the next few years by combining the seismic standards with the ongoing PBS program. The GSA plans to initiate corrective construction work on buildings found with unacceptable seismic risks after obtaining approval from the Congress. The GSA also plans to update seismic design criteria and standards for all GSA new and old buildings.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The National Aeronautics and Space Administration (NASA) contributes to the National Earthquake Hazards Reduction Program (NEHRP) through research and measurements using space techniques for the determination and interpretation of the Earth's crustal movements. The primary emphasis of this effort is centered on the earthquake-prone areas of the western U.S. This program is carried out by the Crustal Dynamics Project (CDP), managed at the Goddard Space Flight Center (GSFC) in Maryland, and the Jet Propulsion Laboratory (JPL) in California, under the direction of NASA's Geodynamics Program Office.

NASA GEODYNAMICS PROGRAM

Satellite geodynamics concerns the use of space technology in the study of the dynamic processes and movements of the solid Earth. The study involves measurements of the Earth's gravity and magnetic fields, the distortions and relative motions of its tectonic plates and the orientation of, and rate of rotation about, its axis. These studies address fundamental questions of geophysics such as the causes of Earth movements and earthquakes, the nature of convection in the mantle, and the origin of the magnetic field.

The use of space technology has helped advance our concepts and models in solid-Earth geophysics. Shortly after the dawn of the space age, tracking data were used to precisely define the shape of the Earth. Since that time, other data have been used to construct a sequence of model representations of the secularly changing magnetic field and global modes of the gravity field. Using this technology, it is now possible to determine the present rate of relative plate motions at the level of about 1 cm per year.

There are exciting prospects for future missions in satellite geodynamics. The Geopotential Research Mission (GRM) is designed to improve gravity and magnetic field models, and new, highly portable geodetic systems based on the Global Positioning System (GPS) and spaceborne laser systems should permit rapid determination of positions with 1 cm precision.

Joint Program for the Application of Space Technology to Crustal Dynamics and Earthquake Research

The global distribution of large earthquakes shows them to be most prevalent along the edges of the major tectonic plates. The relative motions between these plates cause severe distortions at the plate boundries, which result in earthquakes. The measurement of the relative plate motions and crustal distortion along the plate boundaries will contribute significantly to understanding this process.

Direct measurements of plate motions and crustal deformation require geodetic systems capable of measuring long baselines (100-10,000 km) over any terrain with very high accuracy. NASA has been supporting the development of two space-geodetic techniques: very-long-baseline interferometry (VLBI) and satellite laser ranging (SLR). Each of these systems has the capability required for measuring plate motions, crustal deformation, and small changes in the Earth's rotation parameters.

A coordinated Federal program for the application of this space technology to crustal dynamics and earthquake research was established in 1979. The participating agencies are NASA, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), the National Science Foundation (NSF), and the Defense Mapping Agency (DMA). NASA has been leading the technology development, and is the focal point for the initial phase of implementation of VLBI and SLR for crustal dynamics. The NOAA National Geodetic Survey (NGS) is operating the Polaris VLBI network for regular polar motion and Earth-rotation measurements. NGS also operates mobile VLBI systems for very high-accuracy geodetic surveys in North America. The USGS and NSF have prime responsibility for earthquake research investigations. Their interest in utilizing space geodesy is to obtain new and significant measurements relevant to the earthquake process. The DMA has a responsibility for high-accuracy geodetic surveying and mapping for the U.S. military establishment.

Crustal Dynamics Project

By 1979 the developments of SLR and VLBI

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had demonstrated their high-accuracy capabilities for geodetic measurements, and NASA established the Crustal Dynamics Project (CDP) for the application of these space techniques to the study of the dynamic motions of the Earth related to earthquakes. The scientific objectives were to improve knowledge and understanding of:

- Regional deformation and strain accumulation related to large earthquakes in the plate boundary regions in western North America;
- Contemporary relative motions of the North American, Pacific, South American, Nazca, Eurasian, and Australian Plates;
- Internal deformation of continental and oceanic lithosphere plates, with particular emphasis on North America and the Pacific;
- Rotational dynamics of the Earth and their possible correlation with earthquakes, plate motions, and other geophysical phenomena; and
- Regional deformation in other areas of high earthquake activity.

In order to achieve these objectives, an extensive measurement program utilizing both VLBI and SLR is now underway. Frequent high-accuracy measurements of baselines between many stations in active areas near plate boundaries are being made to determine regional deformation and strain accumulation. Baselines between a global set of stations are being measured repeatedly to determine relative plate motions. Repeated measurements of baselines between several stations on the same plate are being made to determine the internal deformation of the plate. Polar motion and Earth-rotation variations are derived from daily measure-

Regional Deformation — Western N. America

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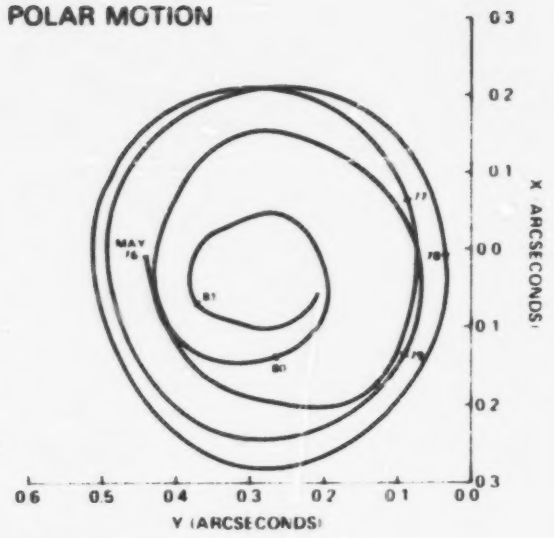


Rotational Dynamics of the Earth

ments with a global set of stations in stable locations.

Four of the five objectives require measurements of motions between selected sites. The approach is to measure repeatedly the vector baselines between these sites over a period of at least 5 years. The average motions are determined from the changes in the vector baselines.

The Space Geodetic Systems

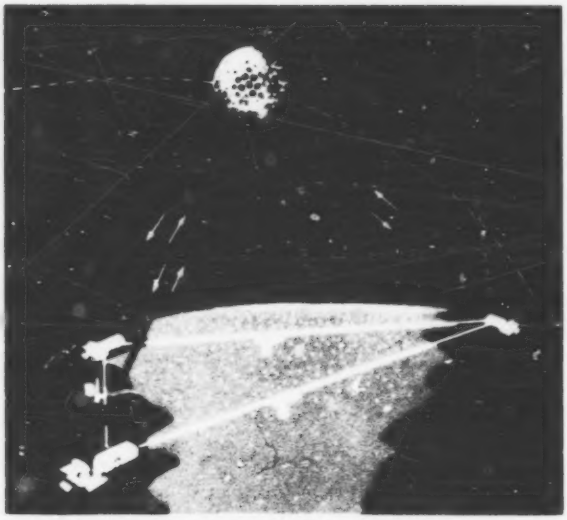
The SLR Systems

The SLR systems measure the round-trip flight time for very short laser pulses to a retroreflector on a satellite. This requires a satellite whose shape and orbit height provide a very stable orbit. The Laser Geodynamics Satellite (Lageos), Starlette, and the Moon are examples of retroreflector-equipped satellites in orbit high enough to be free from serious perturbations caused by effects that are difficult to model (i.e., the complex gravity-field structure due to density inhomogeneities in the Earth, variations in atmospheric drag, etc.). The SLR systems accurately determine ranges to a satellite as a function of time. The ranges from several stations to the same satellite are used in orbit analysis programs to determine the geocentric positions of the stations and the vector baselines between them.

The CDP operates two general types of SLR systems. The first type is fixed and they are used as base stations. The second type is the highly mobile Transportable Laser Ranging System. (TLRS).

The fixed systems include eight MOBLAS (Mobile Laser) systems which, as their name implies, were intended to be mobile systems when they were first conceived 20 years ago. Although they can be relocated with some difficulty, it is much more effective in terms of time and money to use them as base stations. Also included in the fixed systems are three stations which range to the Moon as well as to Lageos. These systems sponsored by NASA are located at McDonald Observatory, Texas; Haleakala Observatory, Hawaii; and Orroral Observatory, Australia.

NASA owns four highly mobile laser systems. TLRS-1 and TLRS-2 which became operational in 1981 and 1983, respectively, have spent much of 1985 being upgraded. These should be opera-



In Satellite Laser Ranging (SLR), ground based stations transmit short intense laser pulses to a retroreflector equipped satellite whose orbit is well known. The round trip time of flight of the laser pulse is precisely measured. This permits accurate determination of the station locations and the baselines (B) between them.

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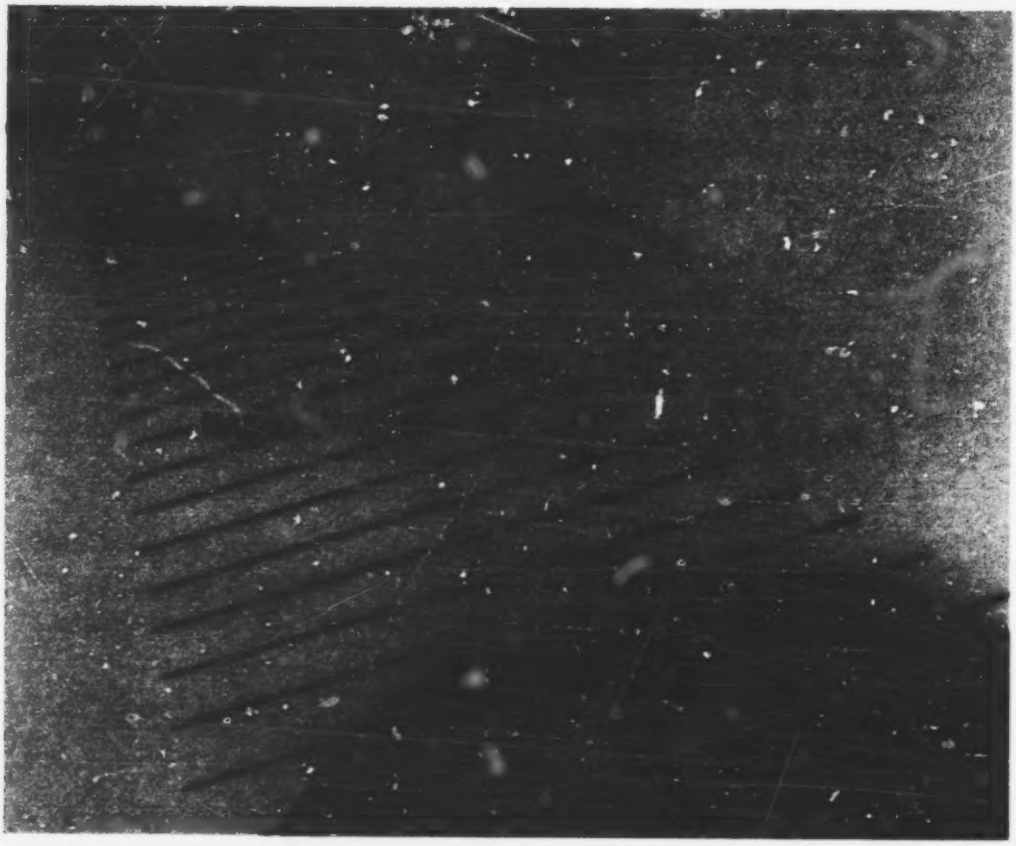

In Very Long Baseline Interferometry (VLBI), signals from distant radio sources (quasars) are recorded simultaneously by antennas which may be up to thousands of kilometers apart. Using hydrogen maser clocks, the difference in arrival time of the radio signals at the antennas is measured, leading to precise beseline (B) determinaitons.

tional by late 1986. In addition, the Delft Technical University in the Netherlands and the Geodetic Research Institute in Germany have developed two highly mobile SLR systems called Modular Transportable Laser Ranging Systems (MTLRS). The German system, MTLRS-1, and the Dutch system, MTLRS-2, are now making measurements in the eastern Mediterranean.

The recently upgraded MOBLAS systems have a range measurement precision of better than 2 cm for a single return and well under 1 cm RMS average for a two minute normal point to Lageos. The similar figures for the highly mobile systems (TLRS and MTLRS) are 7 cm and 2 cm respectively. With laser ranging normal point precisions of under 2 cm, baselines from 200 km to 6000 km long can be determined to a precision of 2 cm to 5 cm.

The VLBI Systems

The VLBI system uses two or more widely separated radio telescopes to observe radiation from extragalactic radio sources, typically quasars, which are effectively fixed points in the sky. The quasar radiation can be thought of as a complicated random signal, and the VLBI observing scheme is simply a process of observing this signal from various points on the surface of the Earth, time tagging its arrival with respect to a local clock at each site, and recording the time-tagged signals on tape. The tapes from the telescopes are sent to a central facility and cross-correlated in pairs. The two tapes contain the identical random signals, plus noise, but time tagged differently because the signal was received at different times. By delaying one tape relative to the other until peak correlation is achieved, the time delay between the arrival

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of the signal at the two sites is found. This is a function of the separation of the two VLBI stations.

NASA-sponsored research scientists developed and deployed the "Mark-III" VLBI system, which is optimized for high-accuracy geodesy. The system was developed with stand-alone subsystems to enable its use in all three configurations of VLBI stations employed by the CDP. These configurations are:

- Fixed VLBI stations with Mark-III VLBI capability permanently located at the stations;
- Transportable VLBI data systems (TVDS) where a transportable Mark-III system is brought in and connected to a fixed antenna for a short-term VLBI measurement; and
- Mobile VLBI (MV) stations where the entire VLBI station, including the antenna, are contained in tractor-trailors for moving from site to site. These MV stations were developed by NASA's Jet Propulsion Laboratory.

The Mark-III VLBI systems have been in operation for several years. The demonstrated precisions for horizontal baseline components is 2 cm for short to medium (200-2000 km) baselines and 3 cm for long baselines, and for the vertical baseline component is 6 cm for short baselines and 3 cm for long baselines.

The Crustal Dynamics Network of SLR and VLBI Stations

The CDP set out in 1979 to implement a global network of fixed and highly mobile SLR and VLBI stations to achieve its scientific objectives; 1984 marked the completion of the Project's implementation of fixed stations. The network consists of stations operated by the CDP, plus stations owned and/or controlled by other groups, under agreements with NASA. The implementation and operation of this network required the participation and cooperation of a large number of organizations both in the U.S. and from other countries all over the world. Eighteen U.S. institutions and 23 foreign institutions are participating in the acquisition, processing, and distribution of this data.

The basic philosophy for implementing the network was to establish, where possible, at least three stations on the stable part of each plate for measurements of relative plate motions and internal plate deformation. These same stations also serve as reference base stations for measurements to highly mobile stations occupying many regional deformation sites along active plate boundaries.

The SLR fixed stations form a good configuration for Lageos orbit determination and for high-accuracy determination of the Earth's polar motion and changes in rotation rate. The SLR stations with lunar capability also form a good configuration for determining polar motion and Earth rotation changes using lunar tracking data. Similarly, fixed VLBI stations operating in North America and Europe form a good network for polar motion and Earth rotation measurements. The test of this new capability for high-accuracy polar motion and Earth rotation measurements was the purpose of the international project to Monitor Earth Rotation and Intercompare Techniques (MERIT) sponsored jointly by the International Astronomical Union and the International Union of Geodesy and Geophysics which was conducted from September 1, 1983, to October 31, 1984.

Of the 36 sites implemented for measurements with the highly mobile SLR and VLBI systems through Fiscal Year 1986, 24 were in the western U.S. There were five mobile VLBI in Alaska with three in Canada and three mobile SLR in Chile with one in Mexico. Some of the western U.S. mobile measurements were at or near fixed VLBI or SLR station locations. The purpose of this is to make duplicate measurement of some baselines with both SLR and VLBI systems in order to check for systematic errors in both systems. The ultimate accuracy of the baseline measurements depends on the level of systematic biases. Since the SLR and VLBI systems have very different error sources and biases, the direct comparison of measurements on the same baselines is a good method for uncovering these problems. The Project has planned on making both SLR and VLBI measurements at about 25 percent of the fixed and highly mobile sites. Based on intercomparisons already conducted, the SLR and VLBI baseline measurements agree with each other within the combined uncertainties of the individual systems. This indicates that the systematic errors are not larger

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than the random errors given earlier for the SLR and VLBI systems.

Recent Measurements and Future Plans

The plate motion and plate stability baselines measured to date, represent about 90 percent of the baselines planned for the CDP. The fixed stations and mobile sites in North America and the Pacific are completed and the emphasis is now on repeated measurements. Most of the planned European stations are operating. VLBI stations at Matera, Italy and Madrid, Spain are expected to be established in the future. The two Australian SLR stations are operating and the NASA Tidbinbilla tracking station will soon have geodetic VLBI capability. New SLR and VLBI stations have begun operations in Japan. China has started operations of a SLR station, and an agreement has been negotiated for China to implement and operate a VLBI station with the CDP. On the Nazca plate, the Easter Island SLR site is operating and a second SLR site on San Felix Island is planned.

The regional deformation measurements in North America in 1982 to 1986 included initial measurements at all planned sites except the newest site in Ensenada, Mexico, which will be occupied in 1987 with one of the highly mobile TLRS.

Up to now there have been no Project measurements of regional deformation started anywhere outside of North America. The Project is planning to join in such measurements in the Mediterranean area. This program is organized by a consortium of institutions from several nations, the Working Group of European Geoscientist for the Establishment of Networks for Earthquake Research (WEGENER), in cooperation with the CDP. The general plan is to use a mixture of NASA and European SLR systems. The SLR base stations will be in: Wetzell, Germany; Graz, Austria; Matera, Italy; Dionysos, Greece, and Jerusalem, Israel. The highly mobile SLR systems, MTLRS-1, MTLRS-2, and TLRS-1, will be deployed to several sites in Greece, Italy, Turkey, and Egypt. The initial measurements are planned for 1987 and the measurements will be repeated in 1988 and 1990.

An agreement between NASA and the German Ministry of Science and Technology (BMFT) provides for NASA to support the WEGENER measurements in the Mediterranean with the loan of a TLRS and in return BMFT would support the NASA North America measurements with the loan of their MTLRS-1. The plan calls for alternate year support through 1990, starting with the visit by MTLRS-1 to the U.S. in 1985 and continuing with the TLRS-1 visit to Europe in 1987 as discussed above.

The Italians are developing a second Lageos to be placed in orbit by a U.S. launched vehicle. Lageos-II will be identical to its predecessor; a passive sphere 60 cm (24 in.) in diameter, weighing 411 kg (903 lbs.) and covered by 426 retroreflectors. It will orbit at the same 6000-km altitude, but with an inclination of 52 degrees instead of the 110 degrees for Lageos-I. This lower inclination will optimize it for the Mediterranean and other lower latitude laser stations. The addition of Lageos-II is expected to improve by a factor of 2, the accuracies of the geodetic quantities produced by Lageos-I alone. Tracking of the two satellites will greatly enhance research in the areas of plate tectonics, crustal deformation and Earth dynamics.

In addition to the laser and VLBI techniques discussed above, NASA and the other agencies are developing the use of the DoD GPS satellites for geodetic measurements. A NASA/JPL developed Global Position System (GPS) receiver called SERIES (Satellite Emission Range Inferred Earth Surveying) participated in interagency comparison tests with two other receiver systems in the desert of southeast California in early 1985.

The use of low cost, portable GPS receivers for the highly accurate measurement of vector baselines will introduce a new era in geodesy. A number of important geophysical questions can now be addressed with this measurement capability due to the potentially large number of observations which can be economically made with a GPS-based system.

The NASA goals for this program are to design and demonstrate a GPS-based measurement system for centimeter geodesy and to accumulate scientifically important data in a key tectonic region, such as central America and the Caribbean. An additional goal is to develop an active

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SUMMARY OF TECTONIC PLATE MOTION RESULTS

PLATES		AVERAGE OBSERVED MOTION (cm/yr)	UNCERTAINTY (cm/yr)	AVERAGE MINSTER JORDAN (cm/yr)
North America To:				
	Australia	-2.3	±0.4	-2.5
	Pacific	2.0	±0.9	1.5
	South America	-1.2	±0.6	-0.8
	Europe	1.7 (1.1)	±0.3	1.7
Australia To:				
	Pacific	-7.0	±0.9	-6.0
	South America	2.7	±0.7	2.4
Pacific To:				
	South America	3.5	±1.4	4.9
Europe To:				
	South America	1.4	±1.5	1.3
Motion Along The San Andreas Fault		6.2	±0.9	5.3

participation in GPS-based geodetic programs by scientific groups residing in North America, the Caribbean and Latin America.

Results

The present standard for global tectonic plate motion is the Minster-Jordan based on paleomagnetic data covering the past several million years. Now for the first time, it is possible to measure contemporary plate motion, using baselines derived from VLBI and SLR data. Using data collected through 1984, the CDP Scientists have developed a set of contemporary plate motion results between five of the major tectonic plates. The nine average observed motions agree with the Minster-Jordan average values within the combined uncertainties of the two techniques.

All data collected and produced under the NASA Geodynamics Program is readily available to the domestic and cooperating international scientific community. The CDP Data Information System (DIS) provides all VLBI and SLR data, raw or processed, on request to approved Crustal Dynamics Investigators, both foreign and domestic. A similar arrangement will be implemented by JPL with respect to the Caribbean GPS Project once it becomes fully operational.

The thrust of the NASA Geodynamics Program is to complete development of advanced space related geodetic techniques for use by NASA; operational survey agencies at the Federal, State, and local level; commercial survey organizations; and cooperating foreign countries. NASA, through the CDP at Goddard and the Caribbean GPS Project at JPL plans to continue at regular intervals, at least through 1990, all of the measurements discussed earlier.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

TSUNAMI WARNING SERVICE

A tsunami, sometimes referred to as a tidal wave or seismic sea wave, may be generated by any mechanism which results in a significant vertical displacement of the ocean's surface over an extended area. In returning to a sea level state-of-equilibrium, a gravity wave system is established which generates a series of waves capable of propagating great distances with an extremely efficient transfer of energy. The potential for destruction is thus not limited to the near source region, but may extend across the entire ocean basin. The most frequent source mechanism is associated with displacement of the earth's crust along a zone of fracture which underlies or borders the ocean floor. The associated earthquake can be detected and measured by seismic instrumentation throughout the world, but not all major coastal or near coastal earthquakes produce tsunamis. The actual generation of a tsunami can only be confirmed by the arrival of the characteristic ocean waves at nearby coastal tidal stations. With a speed of wave propagation in the deep and open ocean of 500 to 1,000 km/hour (300 to 600 miles per hour), a rapid response is necessary to provide a timely warning to coastal areas.

Destructive tsunamis are an infrequent phenomenon, but, once generated, the wave energy is enormous and will propagate across the Pacific Basin to cause destruction on distant shores far removed from the source region. The tsunami associated with the 1960 earthquake in southern Chile travelled 17,800 km across the Pacific to Japan where waves killed 200 people and caused extensive property damage. The same tsunami caused 61 deaths and $24 million damage in Hawaii and over $1 million damage along the west coast of the United States. The costliest tsunami ever to hit the United States was associated with the Prince William Sound, Alaska, earthquake of March 28, 1964. Fatalities totalled 119, and over $94 million in damage resulted in Alaska, California, Hawaii, Oregon, and Washington.

All the coastal areas of the United States bordering on the Pacific Ocean are subject to tsunami destruction. Hawaii is particularly vulnerable, being subject not only to regional tsunamis generated in Hawaii, but also to Pacific-wide tsunamis generated all around the Pacific Basin. South America, the U.S.S.R., and Alaska historically have been the primary source regions for destructive Pacific-wide tsunamis. Major earthquakes in these areas constitute a distant but significant hazard to the United States.

Tsunami Warning Service Operations

The National Weather Service (NWS) is charged with responsibility for the Tsunami Warning Service and for the preparation and distribution of Watches and Warnings of tsunamis that may threaten lives and/or property in and around the Pacific Ocean. The NWS operates and admininsters the Pacific Tsunami Warning Center (PTWC) at Ewa Beach, Hawaii, and the Alaska Tsunami Warning Center (ATWC) at Palmer, Alaska. Program management is the responsibility of the Director, NWS Pacific Region, in Honolulu, Hawaii. Administrative support and facilities are provided by the NWS to the International Tsunami Information Center in Honolulu which operates as a function of the Intergovernmental Oceanographic Commission.

The Tsunami Warning Service requires the participation of many seismic, tidal, communication, and dissemination facilities operated by most of the nations bordering the Pacific. The NWS responsibility for issuing warnings is divided into a regional and Pacific-wide basis. The PTWC provides regional warning services for Hawaii; the ATWC provides regional warning services for Alaska, Canada, Washington, Oregon, and California. The PTWC also functions as the National Tsunami Warning Center responsible for providing Pacific-wide tsunami warning services for all coastal States and other U.S. interests throughout the Pacific.

Seismic Data Acquisition

Evaluation of a major earthquake is the initial phase in Tsunami detection. The first tsunami waves may be hitting the nearest coastline within

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minutes, so a rapid response is mandatory for the issuance of timely tsunami warnings. As Regional Tsunami Warning Centers, both PTWC and ATWC issue local warnings to the appropriate civilian and military agencies based entirely on the earthqake size and location. As the National Tsunami Warning Center, PTWC will issue an initial Watch based on seismic data and upgrade to a Warning upon confirmation of sea level changes from tidal gauges.

Real-time seismic data are required from a network of seismic stations to provide a rapid and accurate determination of epicenter location and earthquake magnitude. Both PTWC and ATWC exchange real-time seismic data via satellite communications with the USGS/National Earthquake Information Center. In this manner the ATWC seismic network is extended to include West Coast stations and the PTWC real-time seismic network extends from the eastern U.S. to the western Aleutians to provide data for a rapid epicenter determination for earthquakes anywhere in the Pacific.

GOES Data Acquisition

The Geostationary Operational Environmental Satellite (GOES) provides the capability for sea level data to be transmitted in a near real-time mode (3 to 5 minutes) from remote Pacific locations to the Pacific Tsunami Warning Center. During Fiscal Year 1986, 17 satellite Data Collection Platforms (DCP's) were installed in addition to the 4 units previously reported for Fiscal Year 1985. These installations are at:

Rarotonga, Cook Islands
Penrhyn, Cook Islands
Baltra Island, Galapagos Islands, Ecuador
La Libertad, Ecuador
La Punta, Peru
Isla Lobos de Afuera, Peru
Arica, Chile
Valparaiso, Chile
Easter Island, Chile
Nuku Hiva, Marquesas Islands, French Polynesia
Kiritimati (Christmas Island), Kiribati
Kanton Island, Kiribati
Tarawa, Gilbert Islands, Kiribati
Ponape, Federated States of Micronesia
Kapingamarangi Atoll, Federated States of Micronesia
Majuro, Republic of the Marshall Islands
Nauru
Honiara, Guadalcanal, Soloman Islands
Rabaul, New Britain, Papua New Guinea
Johnston Island and
Wake Island.

An additional DCP at Funafuti, Tuvalu, is scheduled for field installation by the University of Hawaii before the end of Fiscal Year 1986. GOES transmissions normally occur every 3-4 hours to provide a continuous record of sea level activity for the preceding interval. In addition some DCP's at strategic locations are programmed as event detectors to commence random transmissions on the GOES emergency channel whenever sea level thresholds characteristic of a tsunami are exceeded. PTWC now receives data from these stations within minutes of tsunami impact.

University of Hawaii/Oregon State University Coordination

Under funding from the National Science Foundation, Dr. Klaus Wyrtki of the University of Hawaii has established a Sea Level Network in the Pacific to monitor mean sea level changes. As part of the Tropical Ocean-Global Atmosphere Program (TOGA), Dr. Wyrtki has established the TOGA Sea Level Data Center at the University of Hawaii. Also as part of TOGA, Dr. David Enfield of Oregon State University is installing a network of satellite tide stations along the coast of South America.

By the application of GOES technology to the Tsunami Warning Service, the National Weather Service has established coordination with the University of Hawaii and Oregon State University in the collection of sea level data to use a single DCP at each tide station to satisfy the multiple requirements of the Tsunami Warning Service, the NSF Sea Level Network, TOGA, and the Integrated Global Ocean Services System (IGOSS) Sea Level Pilot Project. With the University of Hawaii and Oregon State University providing funding for field installation, the GOES DCP's installed in South America and in the south and southwest Pacific are programmed to transmit multichannel data to satisfy the research requirements related to mean sea level studies as well as the

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operational requirements of the Tsunami Warning Service.

Mexico Tsunami of September 19, 1985

The magnitude 8.1 Mexico earthquake of 1318Z on September 19, 1985, generated a minor tsunami which was recorded at many tidal stations in Central and South America and in the South Pacific. No significant destruction occurred as a result of the tsunami, even in the near source region, although the earthquake caused major damage and loss of life in Mexico City and other areas.

A Regional Tsunami Watch was issued by the Pacific Tsunami Warning Center and cancelled two hours later based on the evaluation that no potentially destructive tsunami had been generated. Maximum peak to trough sea level fluctuations of 60 cm were reported from El Salvador and Ecuador, with 24 cm waves recorded in Hawaii and 24 cm waves reported from Western Samoa.

Adak Tsunami of May 7, 1986

On May 7, 1986, at 2247Z a magnitude 7.7 earthquake occurred in the Andreanof Islands near Adak, Alaska. A Pacific-wide tsunami was generated which was recorded at tidal stations from Japan to Chile. No tsunami destruction was reported from any location. The Alaska Tsunami Warning Center issued a Regional Tsunami Warning for Alaska, Canada, and the west coast; the Pacific Tsunami Warning Center issued a Tsunami Warning for all Pacific coastal areas. The Warning was cancelled after it was determined that the tsunami posed no destructive threat to the Pacific based on wave arrivals in Hawaii. Maximum peak to trough waves of 175 cm were recorded at Adak, with a maximum of 78 cm recorded at tidal stations in Hawaii. Waves of 38 cm were reported in Japan, 40 cm in New Zealand, and 45 cm in Chile.

Seismological Observatory Operations

In addition to Tsunami Warning Service responsibilities, the Pacific Tsunami Warning Center continues to function as the Hawaii station for the World-Wide Standard Seismograph Network (WWSSN), with all data being routinely collected and forwarded to the U.S. Geological Survey. Digital WWSSN instrumentation has also been installed at the PTWC by the USGS. The Alaska Tsunami Warning Center continues to function as a Regional Seismological Center for Alaska in support of operational and research activities of the USGS and other agencies.

Project GEOSCOPE, sponsored by the Institut National des Sciences de l'Univers and managed by the Institut de Physique du Globe de Paris, has installed a long-period broadband seismological station in Hawaii as part of a global network. This instrumentation is monitored and maintained by the PTWC and provides digital data for the study of the dynamics of the rupture process associated with earthquakes and for a better understanding of the composition and state of the Earth's interior. The future availability of these data on an operational basis in near real-time provides a future possibility of determining the tsunamigenic potential of earthquakes in the Pacific by the rapid estimation of source mechanism and seismic moment.

GEODYNAMIC INVESTIGATIONS

Plate Deformation, Plate Motion, and Earth Orientation by VLBI

During Fiscal Year 1986 the National Geodetic Survey continued to operate three Very Long Baseline Interferometry (VLBI) stations in cooperation with the International Radio Interferometry Surveying (IRIS) program. The IRIS observations provide measurement of polar motion and nutation of the Earth at a 5-day intervals accurate to 1 to 2 milliseconds of arc and measurements of Earth rotation (UT1) on a daily basis accurate to 0.05 to 0.10 milliseconds of time. A sudden change in the IRIS nutation series beginning about September 1985 may be the first detection of free core nutation. The onset of this sudden nutation change agrees closely in time with the magnitude 8.1 Mexico earthquake of September 19, 1985. However, theoretical calculations of the free core nutation excitation to be expected from the earthquake are several orders of magnitude too small to account for the observed motion. Investigations of this change in nutation continue to be given high priority because of the potential for obtaining informa-

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tion about core properties and core-mantle interaction.

Measurements of the distance between the Westford, Massachusetts, and Ft. Davis, Texas, VLBI stations continued to show shortening of the baseline by about 1 cm per year. Calculations indicate that, if this baseline shortening represents response of the North American plate to the forces driving plate motion, the strain energy associated with the apparent compression would be sufficient to cause the intraplate seismicity observed in the eastern United States.

Measurements between the United States and Europe continued to show the North American and Eurasian plates moving apart at rates compatible with those in current plate motion models. Measurements carried out jointly with the University of Bonn, Federal Republic of Germany (FRG) and the National Institute for Telecommunications, South Africa, provided first epoch VLBI measurements to be used to monitor the movements of the African plate relative to the North American and Eurasian plates. This was an important step toward a worldwide VLBI network for global monitoring of the motions of the lithospheric plates.

Regional and Local Crustal Motion Measurements by GPS

NOAA measurements with Global Positioning System (GPS) geodetic receivers in Fiscal Year 1986 consisted of repeat measurements over existing conventional and GPS networks and establishment of new GPS monitoring networks.

An important effort was the establishment of a 14 station GPS network in southern California reaching from Yuma, Arizona, to the Pacific Ocean. The network includes the 10 mobile VLBI stations in this area. Continued monitoring of this network with GPS will be carried out to determine the spatial and temporal variations of deformation across the North American-Pacific plate boundary in southern California. The GPS measurements will initially extend the mobile VLBI network and ultimately replace mobile VLBI for regional crustal motion monitoring in southern California.

GPS measurements were carried out at about 35 stations of an existing conventional horizontal control network in the Imperial Valley between the Salton Sea and the Mexican border. The data from these GPS measurements will be compared with results of the conventional measurements made immediately following the 1979 El Centro earthquake to define post seismic deformation in the area.

Other GPS surveys providing crustal motion information included repeat surveys of the network of 6 VLBI stations in Alaska which were originally observed in 1984, a network of 15 stations near Eastport, Maine, to monitor possible tectonically induced subsidence, and establishment of first epoch measurements for a regional strain network in New England.

Crustal Motion From Conventional Geodetic Data

Analysis of repeat conventional horizontal data in the vicinity of the Ramapo Fault in New York and Connecticut was carried out. This analysis indicated that no statistically significant strains were occuring.

Analysis of repeat leveling in the Imperial Valley of California showed a correlation between vertical motions and block movement by blocks bounded NW-SE and NE-SW faults as defined by seismicity.

An analysis of repeat leveling data provided a set of empirical corrections for the effect of the Earth's magnetic field on leveling instruments with compensators. This will greatly improve the value of leveling data for crustal motion analyses.

NATIONAL GEOPHYSICAL DATA CENTER

The National Geophysical Data Center (NGDC) archives, processes, analyzes, and disseminates earthquake and tsunami hazards data and information to the public, other governmental agencies, and the scientific community. Researchers and engineers studying ways to reduce the earthquake hazard are principal

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users of the data. In Fiscal Year 1986, data bases in seismology and tsunami studies were improved. Seismic data from the U.S. Geological Survey (USGS) and other sources were added to the NGDC archive, and new catalogs of earthquake epicenters were inluded in the Earthquake Data File. Also, several new publications, maps, and other informational products were prepared and made available to the scientific and engineering communities.

Tsunami Program

NGDC, in cooperation with the Institute of Ocean Sciences of the Department of Fisheries and Oceans, Canada, is developing a computerized model to determine travel times of tsunamis in the Pacific Ocean. This is especially important to residents of Pacific coastal areas, who depend on accurate tsunami warnings for early evacuation of their homes during tsunami emergencies. The new model will be based on the NGDC bathymetric data base and on arrival times observed for historical tsunamis and earthquakes. Existing models are based on generalized bathymetry and on minimal information about historical tsunamis and earthquakes. Therefore, it is expected that the model being developed will predict tsunami arrivals more accurately because the data now available to formulate the model are more complete. Results of this study will be published in a joint NGDC-Institute of Ocean Sciences technical paper.

The Historical Tsunami Data Base is continuously updated, principally by abstracting data from published reports on effects of tsunamis. The data base now consists of about 6,600 records, including data on tsunamis that occurred in the Caribbean and Mediterranean Seas and the Atlantic, Indian, and Pacific Oceans. Recent updates to the data base include the addition of city names, geographic coordinates, damage descriptions, and numbers of fatalities from cities that experienced damage from pre-20th century tsunamis. These updates also included wave run-up heights for 2,000 localities, arrival times, observed travel times, and, for comparison, calculated travel times.

Special emphasis has been placed on updating and correcting information on tsunamis that have affected Japan. The Japanese have cooperated in this effort by providing more-accurate data on tsunamis in that country and on the damage they have inflicted. This important data base is useful in preparing maps that depict locations of tsunamigenic earthquakes and paths of the ensuing tsunamis, and in compiling computer lists of damaging tsunamis sorted by event, location, wave height, amount of damage, or other effects.

A technical paper titled "Historical Tsunamis in the Pacific Basin" was presented at the International Symposium on Natural and Man-made Hazards in Quebec City, Canada. The paper examines tsunamis in 10 regions of Pacific Ocean basin and identifies areas: (1) of high seismic and tsunamigenic risk, and therefore most prone to damage from both local and remote tsunamis; (2) where the most property damage has occurred; and (3) where large earthquakes are most likely to generate tsunamis. Results indicate that the Kamchatka-Kuril, Alaska-Aleutians, and South American coast regions have a high potential for generating remote-source tsunamis, and that the area most vulnerable to damage from those tsunamis is Hawaii. Interestingly, the west coast of the United States has sustained the most property damage from tsunamis generated in the Alaska-Aleutians region. Japan has incurred much damage and many fatalities from local historical tsunamis, and therefore should direct attention toward mitigating effects of local tsunamis that are likely to be generated there in the future. Other regions that are prone to devastating local tsunamis include Indonesia, Chile, and Peru.

"Studying historical tsunamis is an important method of mitigating the effects of future tsunamis," according to an NGDC article recently published in the USGS *Earthquake Information Bulletin*. Titled "Tsunamis—Scourge of the Pacific," the article discusses past tsunamis, the Pacific Tsunami Warning System—how it was formed and how it works—and tsunami safety rules for Pacific coast residents. The article concludes that tsunamis, sooner or later, will visit every coastline in the Pacific. Therefore, never go to the beach to watch for a tsunami, because when you see the tsunami wave it is too late to escape!

The Historical Tsunami Data Base is used in many interesting and unusual projects. A West-

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ern Wyoming College professor recently requested information from this data base to study the effects of historical tsunamis on rock artifacts found on Easter Island. After spending a year on the island studying these famous stone statues, he plotted the movement (caused by the 1960 Chilean tsunami) of several huge pieces of the ceremonial site. Because the ceremonial site is probably more than 1,000 years old, the professor believes that the 1960 tsunami may be the first in a millennium to strongly affect this portion of Easter Island.

New Tsunami Data

The Japan Meteorological Agency provided 33 marigrams to the NGDC tsunami analog file. They include records of the tsunamis on August 7, 1984, September 19, 1984, and March 3, 1985. NOAA's Pacific Tsunami Warning Center in Honolulu furnished 20 marigrams recorded at sites throughout the Pacific of the May 7-8, 1986, Alaska tsunami, in addition to marigrams recorded at coastal sites of the September 19, 1985, Mexico tsunami. The Mexico tsunami caused damage at Mazanillo, Lazaro Cardenas, and Zihuatenejo. Estimated wave heights are 3 meters at Zinuztenejo and 2.8 meters at Lazaro Cardenas.

The Pacific Center also provided arrival times from the Alaska tsunami for 62 sites from Adak, Alaska, to Wellington, New Zealand, as well as run-up reports from sites throughout the Pacific. This was perhaps the most thoroughly documented tsunami in history, because new recording equipment had been installed at several Pacific coast sites previous to its occurrence. No damage resulted from the waves, which caused a maximum run-up of 175 cm at several locations. An unofficial report of 3-meter waves in Hawaii was received.

Six tsunamis have been generated in the Pacific region since January 1985. These

PACIFIC TSUNAMIS, 1985-1986

EVENT DATE YR	MO	DA	LAT. (°)	LONG. (°)	RICHTER MAGNITUDE	DEPTH (KM)	MAXIMUM WAVE RUN-UP (M)	SOURCE REGION
1985	03	13	-33.2	- 72.0	7.8	———	1.1	Valparaiso, Chile
	04	13	- 9.2	144.2	6.2	99	———	S. Bali Island, Pacific
	07	13	- 4.4	152.8	7.4	33	1.3	New Ireland
	09	19	18.1	102.3	8.1	28	3.0	Mexico
	09	21	17.8	101.6	7.6	33	1.4	Mexico
1986	05	07	51.1	174.7	7.7	———	1.7	Aleutian Islands, Alaska

tsunamis occurred throughout the Pacific: in Japan, Mexico, Chile, Alaska, Bali Island, and New Ireland. Maximum wave run-up generated by these events ranges from 0.1 to 3.0 meters; magnitude of the earthquakes that generated the events ranges from 6.2 to 8.1. The tsunamis in Mexico and Alaska produced measurable waves throughout the Pacific basin. But effects caused by other tsunamis in Japan and the Pacific Islands, for example, were confined to local areas. Fortunately, none of the tsunamis listed caused destructive waves or fatalities.

Strong Motion Accelerograph Program

Strong-motion records measure the behavior of the ground and manmade structures during an earthquake. They are extremely valuable to the advanced technology of earthquake-resistant design and construction of buildings and other vital structures. During the last fiscal year the holdings of digital strong-motion data at NGDC have increased considerably. Some of the significant additions include:

- New Zealand, records from 27 stations for 14 earthquakes in 1968-84;
- People's Republic of China, records from 81 stations for 10 earthquakes in 1982-84;
- New Hampshire, records from 12 stations for January 19, 1982, earthquake;
- Southern Alaska, records from 23 stations for 23 earthquakes in 1964-83;
- Mexico, records from 11 stations for the great earthquake of September 19, 1985;
- Papua New Guinea, records from 4 stations for 2 earthquakes in March and December 1983;
- Guerrero, Mexico, records from 14 stations for 3 earthquakes in September 1985;
- Taiwan, Republic of China, records from 37 stations for 4 earthquakes in 1983;
- Italy, several records for earthquakes between 1972-76.

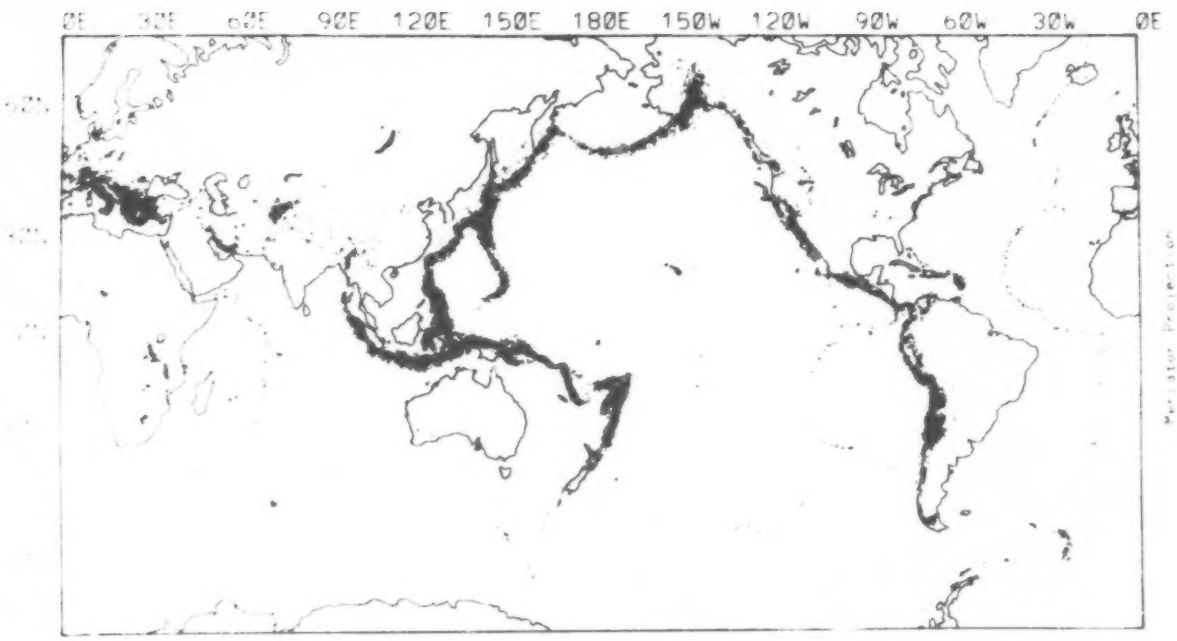
The accelerograph data received for the 1985 Mexican earthquake are significant to scientists because of the large Richter magnitude and the severe effect on life and property—9,500 fatalities, 30,000 injuries, and more than 100,000 homeless in parts of Mexico City and in several States of central Mexico. The magnitude 8.1 event caused property damage estimated at $4 billion. Many of the buildings damaged in Mexico City had 8 to 18 stories, which indicates possible resonance effects; horizontal ground accelerations of 2 seconds' period were recorded at several sites.

This earthquake was caused by subduction of the Cocos Plate beneath the Pacific coast of Mexico, the most easily monitored subduction-thrust fault in the Western Hemisphere. The earthquake occurred in the Michoacan seismic gap, a zone which had been identified as having high seismic potential. Because of this, a large earthquake was anticipated and an array of strong-motion accelerographs had been installed in the seismic gaps of the coast of Mexico: Guerrero and Michoacan. Because of the foresight of U.S. and Mexican scientists working in the fields of seismology and earthquake engineering, significant strong-motion records were recovered, and this event has become the best documented subduction-thrust earthquake to date.

Accelerograms from the Guerrero accelerograph array were made available by the Institute of Geophysics and Planetary Physics of the University of California, San Diego, and the Instituto de Ingenieria at the Universidad Nacional Autonoma de Mexico, Mexico City. The Instituto de Ingenieria also provided strong-motion records recovered from accelerograph networks maintained in the valley of Mexico City and surrounding areas. The records from Mexico City came from instruments located on a variety of lithological foundations and on several manmade structures.

The New Hampshire earthquake was felt by residents over an area of about 127,000 sq km in seven States and Canada. The magnitude 4.7 event caused minor damage in Massachusetts, New Hampshire, and Vermont, and minor aftershocks occurred in January, February, and December. Its significance to the NGDC Strong-Motion Data File is apparent, as the strong-motion data are the first records from the New England region to be archived in this important data base.

Several records from the Strong-Motion Seismic Array located on the Shumagin Islands,



Seismicity of the Earth, 1979-85. Earthquakes Shown Are Magnitude 4 and Larger.

Alaska, were added to the archive. These records are from subduction zone earthquakes that occurred between June 1964 and early 1983, and include recordings from earthquakes beneath Puget Sound, Washington. Many of the ground-motion records from Alaska could be applied, with little modification, to engineering projects in the tectonically similar environment of the Washington-Oregon coastal regions.

Strong-motion records recovered from earthquakes in the Italian Peninsula that occurred between June 1972 and June 1976 were included in the file. The records are from instruments installed and maintained by the ENEA-ENEL Commission on Seismic Problems Associated with the Installation of Nuclear Plants. The ENEL accelerograph stations are located in those areas of Italy that have the highest probability of recording earthquakes of intensity equal to or higher than Intensity VI on the MKS Intensity Scale.

Earthquake Data Base

Responsibility for analog and digital seismograms, including historical seismograms, was assumed by USGS. This responsibility also includes providing seismogram services to the scientific community. The Seismogram Browse File (which consists of 86 file cabinets of microfilmed records) was shipped to USGS headquarters in Reston, VA; the master file of microfilmed seismograms (15 million film chips and microfiche) was delivered to the USGS at the Denver Federal Center; and all original historical seismograms (about 3,000 station-months of data) were given to USGS.

A new publication recently issued by NGDC and appropriately titled *Summary of Earthquake Data Base*, KGRD No. 21, provides documentation and statistics for the NGDC Earthquake Data Base, and describes all products now available using that data. This permits users to have a

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better understanding of the data accuracy, limitations, and completeness. The Earthquake Data Base, the principal source for information on the occurrence of earthquakes, holds information on more than 550,000 events recorded worldwide from 2100 B.C. to the present. The data base comprises many files of data structured into several worldwide and regional files. This new publication contains five tables of statistics that document the data base, two figures that illustrate NGDC's computer-plotting capability, and seven appendixes that provide ancillary information about the data base (e.g., definitions of codes, abbreviations).

Significant Earthquakes

A computerized list of significant earthquakes in the United States from the year 1812 was compiled. The list includes information on about 150 earthquakes that fall in one or more of the following categories: Modified Mercalli Intensity 8 or larger, Richter magnitude 7 or larger, one or more fatalities, and (or) $1 million or more property damage. Preliminary statistics show that the United States has sustained about $4.3 billion property damage and 1,478 deaths from destructive earthquakes since 1812. California leads in both categories: $2.7 billion damage and 995 deaths. Alaska is second: $1.2 billion damage and 309 deaths.

Other Data Products

To carry out its responsibility for providing educational and informational data to the scientist, educator, and general public, NGDC has prepared several sets of 35-mm slides that illustrate important aspects of the geologic hazard. Availability of this product has been announced using mail lists held at NGDC and through advertisements and informational articles in several journals. Each set of slides contains twenty 35-mm color and (or) black-and-white slides on

FATALITIES CAUSED BY EARTHQUAKES IN THE UNITED STATES FROM EARLIEST HISTORY TO 1986 (TOTAL = 1,1478)

YEAR	DATE	TIME UT	EPICENTER DEG	EPICENTER DEG	MAG.	H KM	MM INT.	LOCATION	SOURCE	NO. OF DEATHS	DAMAGE* ($)
ALASKA (136):											
1958	0710	06 15 51.0	58.6	137.1 W	7.9	060	11	Lituya Bay, AK	EQH,P	5	———
1964	0328	03 36 14.0	61.04	147.73W	8.3	033	10	Prince William Sound, AK	EQH	131	1.1 Billion
CALIFORNIA (995):											
1812	1208	15 00					09	Southern California	EQH,P	40	———
1868	1021	15 53	37.5	122. W			10	Hayward, CA	EQH,P	3	1.1 Million
1872	0326	10 30	36.5	118. W			11	Owens Valley, CA	EQH,P	27	0.8 Million
1899	1225	12 25	33.5	116.5 W			09	Southern California	EQH,P	6	———
1906	0418	13 12	38.	123. W	8.3	025	11	San Francisco, CA	EQH,P	700	1.7 Billion
1915	0623	03 59	32.8	115.5 W	6.2		08	Imperial Valley, CA	EQH,P	6	2.9 Million
1925	0629	14 42 16.0	34.3	119.8 W	6.3		09	Santa Barbara, CA	EQH,P	13	26.4 Million
1926	0629	23 21	34.5	119.5 W			07	Santa Barbara, CA	EQH,P	1	———
1932	0606	08 44 22.0	40.75	124.30W	6.4		08	Humboldt County, CA	EQH,P	1	———
1933	0311	01 54 07.8	33.58	117.98W	6.3		09	Long Beach, CA	EQH,P	115	132 Million
1940	0519	04 36 40.9	32.73	115.45W	7.1		10	Imperial Valley, CA	EQH,P	9	19.8 Million
1952	0721	11 52 14.0	35.00	119.03W	7.7	060	11	Kern County, CA	EQH,P	14	198 Million
1954	1221	19 56 27.5	40.80	124.08W	6.6		07	Eureka, CA	EQH,P	1	6.9 Million
1955	1024	04 10 44.0	38.0	122.1 W			07	Oakland, CA	EQH,P	1	3.3 Million
1971	0209	14 00 41.6	34.41	118.40W	6.4	008	11	San Fernando, CA	EQH	58	500 Million
HAWAII (236):											
1946	0401	12 28 58.0	52.8	162.5 W	7.4		06	Tsunami Damage From Alaska EQ	EQH,P	173	61.2 Million

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FATALITIES CAUSED BY EARTHQUAKES IN THE UNITED STATES FROM EARLIEST HISTORY TO 1986 (TOTAL = 1,1478) (Continued)

YEAR	DATE	TIME UT	EPICENTER DEG	EPICENTER DEG	MAG.	H KM	MM INT.	LOCATION	SOURCE	NO. OF DEATHS	DAMAGE* ($)
1960	0522	19 11 17.0	39.5 S	74.5 W	8.3	060		Tsunami Damage From Chile EQ	USE,P	61	181 Million
1975	1129	14 47 40.3	19.34	155.03W	7.2		08	Hawaii	EQH	2	4.1 Million
IDAHO (2):											
1983	1028	14 06	44.4	114. W	7.0	010	07	Idaho	PDE	2	9.0 Million**
MISSOURI (SEVERAL):											
1811	1216	08 15	36.	89. W	8.0		12	Missouri	EQH,N	Several	——
1812	0123	15 00	36.3	89.6 W	7.8		12	Missouri	EQH,N	Several	——
1812	0207	09 45	36.5	89.6 W	8.2		12	Missouri	EQH,N	Several	——
MONTANA (32):											
1935	1019	04 48 03.0	46.6	112. W	6.3		08	Helena, MT	EQH,P	2	9.9 Million
1935	1031	18 37 49.0	46.62	111.97W	6.0		08	Helena, MT	EQH,P	2	3.0 Million
1959	0818	06 37 15.0	44.83	111.08W	7.1		10	Hebgen Lake, MT	EQH,P	28	26.4 Million
SOUTH CAROLINA (60):											
1886	0901	02 51	32.9	80. W			10	Charleston, SC	EQH,P	60	75.3 Million
UTAH (2):											
1934	0312	15 05 40.0	41.5	112.5 W	6.6		08	Kosmo, Utah	EQH,P	2	——
WASHINGTON (15):											
1949	0413	19 55 43.0	47.25	122.50W	7.0		08	Puget Sound, WA	EQH,P	8	82.5 Million
1965	0429	15 28 43.3	47.4	122.3 W	6.5		06	Puget Sound, WA	EQH,P	7	28.7 Million

* = *Adjusted to 1979 Dollar Value*

** = *1983 Dollar Value*

B = *Meyers, Herbert, R. J. Brazee, J. L. Coffman, and S. R. Lessig, 1976: an Analysis of Earthquake Intensities and Recurrence Rates in and near Alaska, NOAA Tech. Memo EDS NGSDC-3, NOAA, Boulder, Colo., 101 p.*

EQH = *Coffman, Jerry L., Carl A. Von Hake, and Carl W. Stover, 1982: Earthquake History of the United States, Pub. 41-1, Rev. Ed (with Supplement through 1980), NOAA-USGS, Boulder, Colo.. 258 p.*

N = *Nuttli, Otto W., 1979: Seismicity of the Central United States, Reviews in Engineering Geology, V. IV, Geological Society of America, pp. 67-93.*

P = *Coffman, Jerry L., 1969: Earthquake Investigation in the United States, C&GS Special Pub. 282, U.S. Dept. of Commerce, ESSA (now NOAA), Washington, D.C., p. 51-52.*

PDE = *U.S. Geological Survey, Preliminary Determination of Epicenters, Various Issues, U.S. Government Printing Office, Washington, D.C.*

USE = *U.S. Geological Survey, United States Earthquakes, Various Issues, U.S. Government Printing Office, Washington, D.C.*

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the following subjects: (1) Earthquake Damage (General); (2) Earthquake Damage to Schools; (3) Earthquake Damage to Transportation Systems; (4) Earthquake Damage, Mexico City, September 19, 1985; (5) Earthquake Damage, San Francisco, April 18, 1906; (6) Tsunami (General); (7) Volcanoes in Eruption; and (8) Volcanic Rocks. Each set of slides includes a list of descriptive captions and photograph credits.

The "Isostatic Residual Gravity Map of the United States" was issued jointly by NGDC and USGS. The single-color map was produced at a scale of 1:2,500,000 on a clear plastic base, which will allow it to be overlaid on other standard maps, including geologic, tectonic, magnetic, and basement maps of the United States. This facilitates data integration and interpretation, and will be invaluable in evaluating the tectonic and structural composition of geologic formations in the conterminous United States. The digital data used to generate this map have been appropriately formatted for use by the scientific community.

NGDC is preparing jointly with USGS and others a seismicity map for the Decade of North American Geology. USGS has developed a comprehensive data base that includes data from global, regional, and local earthquake catalogs. This data base will be provided to NGDC on magnetic tape for processing and plotting.

The second volume of a planned multivolume set of seismograph station directories, *Directory of World Seismograph Stations, Volume II. East Asia—China, Japan, Korea, and Mongolia* was issued by World Data Center (WDC)-A for Solid Earth Geophysics (collocated with NGDC). The 200-page report and eight appendixes provide the geographic location of seismograph instruments, their technical characteristics, dates of operation, and a note on availability of records. WDC-A published Volume I of this series (covering the Americas) in October 1980. The information contained in these volumes is fundamental to data exchange, and to science.

Volume II of a comprehensive catalog of hydrological phenomena associated with volcanoes was issued by WDC-A. The first volume (published in 1984) listed submarine volcanoes, new volcanic islands, tsunamis, seiches, and base surges related to volcanic events from antiquity through 1899. The present volume *(Catalog of Submarine Volcanoes and Hydrological Phenomena Associated with Volcanic Events)* discusses similar phenomena that occurred from January 1, 1900, through 1959.

Other Projects Related to Earthquake Hazards

As part of a continuing program to support both hazards investigations and resource exploration, NGDC has received seismic-reflection data for two areas in Mississippi and Louisiana from the U.S. Department of Energy Salt Repository Office. The data were collected during the evaluation of onshore salt domes for disposal of high-level nuclear waste. Well-log data for these areas also will be deposited at NGDC for dissemination to the public. Other areas that have been evaluated for possible use are in the Texas Panhandle, Paradox Basin, Utah, and areas in Nevada and eastern Washington.

NGDC and USGS have jointly prepared a draft of new guidelines for exchange of seismological data through World Data Centers. This draft will be reviewed by the International Association of Seismology and Physics of the Earth's Interior (IASPEI) for input to the International Association of Scientific Union's Panel on World Data Centres. The final guide will be published in 1987 along with guides for other geophysical disciplines.

The proceedings of the IASPEI/UNESCO Symposium on Historical Seismograms and Earthquakes (August 1985) have been compiled, reviewed, and edited by the staff of NGDC, USGS, and the Earthquake Research Institute of the University of Tokyo. The results, which will be published in 1987, will include sections on (1) earthquake data analysis; (2) historical earthquakes and catalogs; and (3) historical seismograms.

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TENNESSEE VALLEY AUTHORITY

In Fiscal Year 1986, the Tennessee Valley Authority (TVA) continued various programs to evaluate earthquake hazards at its nuclear, hydro, and power transmission facilities. In addition, TVA has maintained its Seismic Monitoring Program to help define the seismicity of the Tennessee Valley region. In October 1985, TVA hosted the annual meeting of the Eastern Section of the Seismological Society of America which included several talks about ground motion and earthquake hazards reduction. TVA was also a financial sponsor for the Third U.S. National Conference on Earthquake Engineering held in Charleston, South Carolina, in August 1986.

INTERAGENCY COOPERATION

TVA participates on the Interagency Committee on Seismic Safety in Construction, which is part of the National Earthquake Hazards Reduction Program; works with the Interagency Research Coordinating Conference to review research projects in seismology, earthquake engineering, and soil or rock engineering; and exchanges seismologic data with other Federal agencies, including the U.S. Army Corps of Engineers, U.S. Geological Survey, and Department of Energy.

PARTICIPATION IN INDUSTRY RESEARCH

TVA is a member of the Seismicity Owners Group (SOG) which was formed in response to urging by the Nuclear Regulatory Commission (NRC) that the utility industry develop methods for estimating the probability of exceeding seismic design inputs for nuclear plants in the eastern United States. The need for probabilistic assessment developed because the NRC's principal advisor on seismic issues, the U.S. Geological Survey, changed its position on the importance of large, historic earthquakes for seismic design. Upon being notified of the USGS's change in position, the NRC formed a plan to reassess the seismic design basis at every site eastward of the Rocky Mountains using a probabilistic approach, and suggested that the utilities should do the same for their individual sites using a utility-developed methodology. In 1983, the Electric Power Research Institute (EPRI) developed a program plan, and the impacted utilities, including TVA, organized the SOG to jointly sponsor the research with EPRI. In Fiscal Year 1986, the methodology was completed, and a topical report was submitted to the NRC. Review of the report and interaction with the NRC will continue into Fiscal Year 1987.

STUDIES RELATING TO MAJOR FACILITIES

Specific ongoing TVA studies relating to regional seismicity and earthquake hazards reduction at major facilities include:

- Regional seismic monitoring program.
- Strong motion instrumentation located at each of TVA's three completed nuclear plants, two sites in the Mississippi Valley Region, and two sites in east Tennessee.
- Emergency earthquake reaction plan for nuclear plants.
- Probabilistic risk assessments to define seismic margins for nuclear plants.
- Ground motion studies for hydro facilities.
- Catalog of historical earthquakes in the Tennessee Valley region.

TVA completed the fifth year of a 7-year program to make in-depth evaluations of 21 of its dams to determine compliance with *Federal Guidelines for Dam Safety*. Six of the dams are being evaluated for seismic related concerns. Studies for the structural stability of Fontana Dam, TVA's largest concrete gravity dam, have been completed; and strengthening of the upper part of the dam is planned in 1987 and 1988. Studies to evaluate seismically induced loss of strength (liquefaction) in embankment foundations at Kentucky and Fort Loudoun Dams are well advanced. Preliminary studies to evaluate liquefaction of other embankment foundations at Guntersville, Beech, and Pickwick dams are in progress. Fourteen final emergency action plans for 30 TVA dams have been completed. Additionally, 16 interim emergency action plans are in place for 17 dams. Plans are revised annually.

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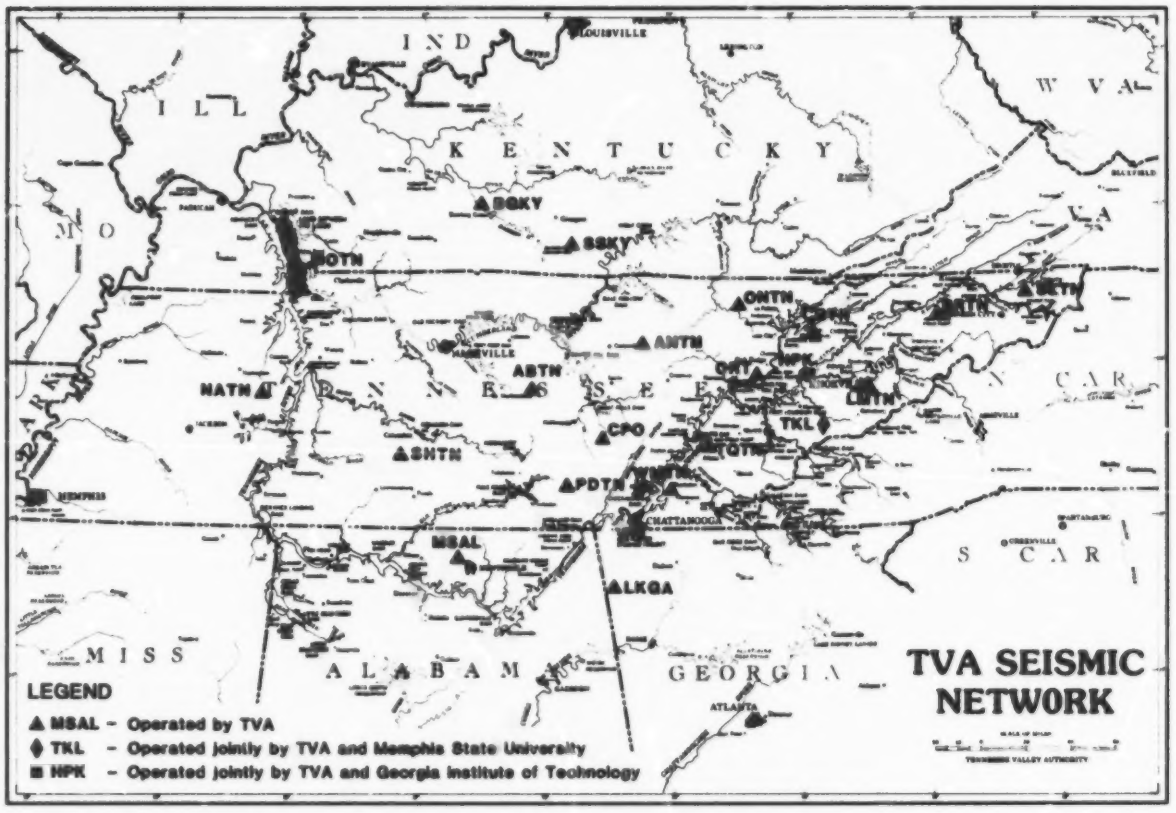

Tennessee Valley Authority seismic network as of July 1986

A seismic analysis of a new 500-kV substation in Maury County, Tennessee, was completed in Fiscal Year 1986. The analysis considered seismic forces and provided details for anchoring all equipment to its foundation or structure. A seismic analysis of structures for a new 500-kV transmission line crossing of the Mississippi River at Richardsons Landing, Tennessee, was also performed as a function of the structure design.

SEISMIC MONITORING PROGRAM

Fiscal Year 1986 was the fifth year of TVA's Seismic Monitoring Program. The purpose of the program is to define the relative frequency, characteristics, mechanisms, and probable future locations of regional earthquakes.

TVA now records data from 21 seismic stations in Tennessee, Alabama, Georgia, and Kentucky. The data recorded at these stations are helping to define the seismicity of the TVA region and to project the expected seismic risk for individual TVA facilities.

TVA continues to provide graduate study grants to Virginia Polytechnic Institute and State University, the University of Kentucky, and the Tennessee Earthquake Information Center (a department of Memphis State University). These grants provide the means for TVA to integrate its data with the localized seismic networks of institutions and universities, which in turn provide a broad data base for understanding the regional seismicity.

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VETERANS ADMINISTRATION

Veterans Administration (VA) concerns for reducing seismic hazards were intensified after the collapse of the VA hospital at Sylmar during the San Fernando Earthquake of 1971. Current VA program activities correct several types of seismic hazards and deficiencies in VA facilities to achieve the following objectives:

- Safeguard patients, staff, and visitors at VA medical centers, clinics, nursing homes, regional offices, supply depots, and data processing centers.
- Protect persons, buildings, and equipment during and after an earthquake.
- Assure continuity of medical care and/or operations and provide emergency utilities services.
- Assist the community and the Nation.

During Fiscal 1986, the VA continued to progress toward meeting these goals and ensuring that critical VA facilities will withstand a major earthquake. Major alterations have been made to strengthen deficient structures and building systems and to safeguard furniture, equipment, and supplies.

VA earthquake hazard mitigation efforts include a wide range of programs to:

- Anchor mechanical, electrical, and plumbing equipment to prevent them from being dislodged or disrupted during an earthquake.
- Install an emergency radio network to provide direct communication between any VA facility in California and any other VA facility in the United States.
- Establish restoration priorities through the National Communications System.
- Coordinate national medical responses with the public/private sector network to provide care to earthquake victims.
- Provide emergency utility services especially water and electrical power.
- Design special earthquake-resistant features for equipment, furniture, and supplies to assure that VA Medical Centers can function in the post-earthquake period.
- Conduct earthquake drills.

Seismic risk level evaluations for maximum design peak accelerations at six specific sites were recently updated by geotechnical studies in conjunction with proposed projects at those specific sites.

VA Facilities at eight high seismic risk sites have been undergoing site studies within the past five years for possible deficiencies based on VA seismic requirements. These VA medical centers are at Palo Alto (two facilities), Los Angeles, Reno, Livermore, Martinez, Long Beach, and San Francisco. Three of these facilities had site studies before the adoption of VA seismic requirements, Handbook H-08-8, in 1973. The remaining five facilities had not been evaluated because the dates of their design and construction implied that they complied with the 1970 Uniform Building Code seismic provisions. Some VA buildings have also been demolished primarily because of seismic deficiencies at Livermore, Palo Alto, and Los Angeles. Other VA buildings have been strengthened at Los Angeles for an intended limited period of their occupancy. For planning and recording seismic corrections to VA facilities, a "Status Summary" and a "Statement of Priorities" are periodically updated.

The VA Seismic Design Handbook, H-08-8, *Earthquake Resistant Design Requirements for VA Hospital Facilities* has recently been edited and simplified, and a final draft is now being prepared for publishing.

VA maintains an active Advisory Committee on Structural Safety including leading seismic experts with emphasis on earthquake hazard mitigation. The VA Director of Civil Engineering Service also serves as the ICSSC representative on the Board of Directors of the FEMA sponsored Building Seismic Safety Council.

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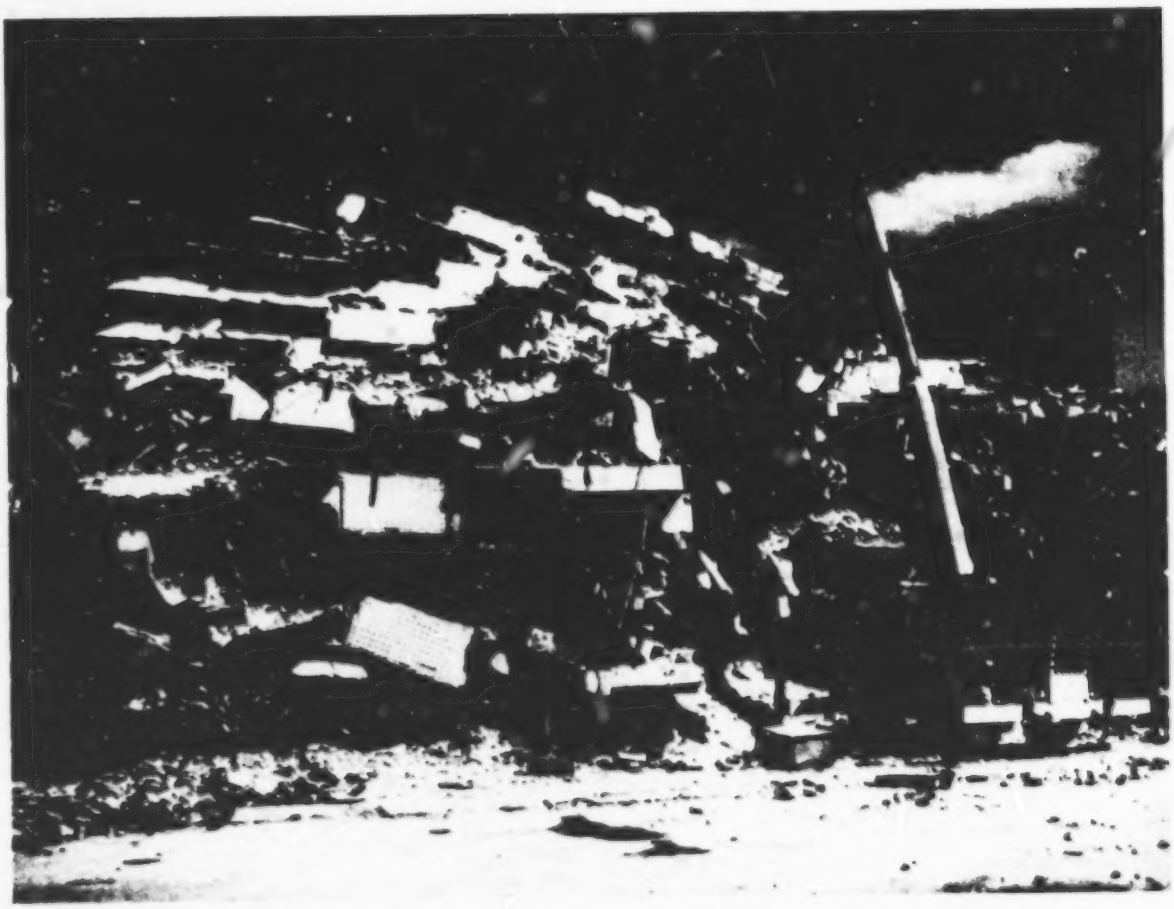
INTERAGENCY COMMITTEES



1985 Mexico earthquake. Several hundred people died in the complete collapse of the maternity building of the Juarez Hospital. Rescue operations were carried out primarily by tunneling into the debris between floor slabs.

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INTERAGENCY COMMITTEE ON SEISMIC SAFETY IN CONSTRUCTION

In 1978, the Interagency Committee on Seismic Safety in Construction (ICSSC) was established as part of the NEHRP to assist Federal departments and agencies involved in construction to develop earthquake hazard reduction measures for incorporation in their ongoing programs.

In meeting its responsibilities, the ICSSC cooperates with State and local governments and private organizations in developing nationally applicable earthquake hazard reduction measures. It is represented on the Board of the Building Seismic Safety Council (BSSC) by the Veterans Administration and participates on BSSC technical committees.

Using consensus procedures, the ICSSC recommends earthquake hazard reduction practices suitable for use by Federal agencies. Each Federal agency may adopt these recommendations, or modifications thereof, as required practices through the use of established Federal procedures for implementing regulations.

All Federal departments and independent agencies that are involved in construction are invited to participate in the ICSSC which currently has a membership of 26. Each participating department or independent agency is represented by a senior person. Additional Federal agency personnel serve on technical subcommittees. Persons from the private sector may be invited to participate in ICSSC activities as observers. The ICSSC is chaired by the NBS.

The ICSSC has successfully balloted a proposed Executive Order, *Seismic Safety of Federal and Federally Assisted or Regulated Construction* which will be submitted to the Interagency Coordination Committee for processing. The proposed order defines actions to meet the requirements of the National Earthquake Hazards Reduction Act of 1977. Additionally, the ICSSC has completed balloting of *Seismic Design Guidelines for Federal Agencies*. These guidelines will be published as a recommended practice for Federal agencies.

The technical program of the ICSSC is conducted by five subcommittees:

- Subcommittee 1: Standards for New and Existing Buildings
  National Bureau of Standards, Chair.

Subcommittee 1 recommends seismic design and construction standards for new and existing Federal buildings, their appurtenances and nonstructural components; and develops strategies and techniques for the identification and correction of existing seismically hazardous buildings.

The subcommittee has prepared the report *Seismic Design Guidelines for Federal Agencies* which has received approval for publication as a recommended practice for Federal agencies. The subcommittee prepared a draft report, *Economic Aspects of Modifying Seismic Design Guidelines for New Buildings for Use by Federal Agencies*. The subcommittee has prepared a draft report on existing buildings and has distributed the draft for review and completion in 1987.

- Subcommittee 2: Lifelines
  Federal Highway Administration, Chair.

Subcommittee 2 identifies existing guidelines or standards for seismic design, construction, and retrofit of energy, transportation, water, and telecommunication systems; recommends Federal adoption of such standards when found adequate; encourages development of new standards where there are significant omissions; and studies techniques for evaluating the seismic vulnerability of existing lifelines and for improving their resistance to seismic effects and their ease of repair. In addition, the subcommittee considers strategies by which to identify those lifeline facilities important in the emergency, immediate recovery, and long-term economic recovery periods and provides guidance for appropriate levels of seismic protection for each type.

The subcommittee has engaged a contractor to produce an educational video tape aimed at

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decision makers in the public and private sectors who have direct responsibility for power and communications facilities. The production will identify the earthquake hazard, indicate the consequences of poor seismic performance of their lifeline facilities, and highlight the availability of cost effective methods for mitigating the effects of earthquakes on lifelines.

- Subcommittee 3: Evaluation of Site Hazards
  U.S. Geological Survey, Chair.

Subcommittee 3 establishes guidelines, procedures, and criteria for site selection and the evaluation of seismic risk and seismically induced geologic hazards to Federally funded, assisted, and regulated construction sites. Hazards that are considered include seismicity, ground shaking, surface faulting, and other tectonic deformation, liquefaction, landslides, and tsunamis.

The subcommittee published its fifth technical report, *Tsunamis — Hazard Definition and Effects on Facilities*. A sixth report, *Site Amplification in Earthquake-Resistant Design* is being prepared.

- Subcommittee 4: Seismic Practices for Federal Domestic Assistance, Leasing, and Regulatory Programs
  Environmental Protection Agency, Chair.

Subcommittee 4 develops strategies for implementation of appropriate standards for earthquake-resistant design and construction of structures and facilities involving Federal domestic assistance (aid, grant, loan, mortgage insurance), leasing, and regulatory programs. The subcommittee deals primarily with policy matters related to application of mandatory standards or guidelines for Federal domestic assistance and leasing and regulatory programs, with consideration of State and local codes. Recommendations are formulated for the implementation of mandatory standards and guidelines and for required regulatory procedures that can be adopted by individual agencies. Specific requirements and exceptions to the mandatory standards and guidelines are indicated for Federal assistance and leasing programs.

The subcommittee has been studying cost-effective procedures for implementing the proposed Executive Order, *Seismic Safety of Federal and Federally Assisted or Regulated Construction*. The subcommittee has prepared a draft report, *Proposed Guidelines and Procedures for Implementation of Proposed Executive Order on Seismic Safety*. The draft report is under review for possible recommended model administrative procedures for Federal agencies.

- Subcommittee 5: Post-Earthquake Response Investigations
  National Bureau of Standards and
  U.S. Geological Survey, Co-Chair.

Subcommittee 5 collects data relevant to the performance of Federal facilities in strong, damaging earthquakes. The subcommittee will develop guidelines for conducting post-earthquake investigations and maintain an up-to-date procedures manual including all existing Federal procedures, and representative State, local, and private sector procedures with respect to post-earthquake response. Activities include: general assessments; deployment of and data collection from instruments; conduct of certain in-depth structural performance studies; providing technical assistance to affected Federal agencies and providing technical supports for those Federal officials responsible for carrying out the National Plan for Response to Catastrophic Earthquakes.

The subcommittee has prepared a draft document, *Post-Earthquake Response Procedure* and has distributed the draft to ICSSC members for their review.

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SUBCOMMITTEE ON FEDERAL EARTHQUAKE RESPONSE PLANNING

The Federal Emergency Management Agency chairs the interagency Subcommittee on Federal Earthquake Response Planning of the Interagency Coordination Committee. As a mechanism on which to build a base for Federal response to a catastrophic earthquake, this subcommittee was established in Fiscal Year 1982 and was charged with developing the capability of the Federal Government to respond to a catastrophic earthquake to assist State and local governments with lifesaving and property protection operations.

This subcommittee guides the development of the framework and strategies upon which the National Plan for Federal Response to a Catastrophic Earthquake is based. This Plan will be described further under FEMA's earthquake program activities. Although the National Plan has been published, the Subcommittee will continue as the coordinating mechanism for maintenance of the Plan and for conducting regional earthquake response planning and exercising activities in all regions.

FEMA Director, project staff, and Subcommittee on Federal Earthquake Response Planning.

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INTERAGENCY COMMITTEE ON DAM SAFETY

The Interagency Committee on Dam Safety (ICODS), chaired by FEMA, serves as a focal point for 20 agencies involved in various aspects of dam safety. The agencies, through Departmental representation are members of the ICODS. Members include: Department of Agriculture, Department of the Army, Department of Energy, Department of Interior, Department of Labor, Federal Energy Regulatory Commission, International Boundary and Water Commission, Nuclear Regulatory Commission, Tennessee Valley Authority, and FEMA.

The purpose of ICODS is to encourage the establishment and maintenance of effective Federal and State programs intended to assure dam safety for protecting human life and property. The Committee's purpose is achieved through coordination and information exchange among agencies sharing common problems and having responsibilities for any aspect of dam safety.

Subcommittees of ICODS address a variety of issues including preparation of Emergency Action Planning Guidelines, research for dam safety, training, and technical guidelines.

During Fiscal Year 1986, an ICODS Working Group completed "Proposed Federal Guidelines for Earthquake Analyses and Design of Dams" to provide consistency in handling earthquake analyses and seismic safety design among the various Federal agencies involved in the planning, design, construction, operation, maintenance, and regulation of dams. The guidelines do not represent standards but rather, are intended for use as general guides that recognize the difference in mission and diversified location of the various agencies and allow flexibility as the state of the art in earthquake engineering continues to develop.

ICODS and FEMA have developed several guidelines supportive of dam safety. These include:

- *Emergency Action Planning Guidelines for Dams*, Subcommittee on Emergency Action Planning, Interagency Committee on Dam Safety;
- *Federal Guidelines for Selecting and Accommodating Inflow Design Floods for Dams*, Working Group on Inflow Design Floods, Interagency Committee on Dam Safety;
- *Federal Guidelines for Earthquake Analyses and Design of Dams*, Design Earthquake Task Group, Interagency Committee on Dam Safety;
- *Financing Dam Safety Projects*, Roger E. Hamlin and William Reiske III for FEMA;
- *National Dam Safety Program—A Progress Report*, State and Local Programs & Support Directorate, FEMA;
- *Report on Review of State Non-Federal Dam Safety Programs*, Dr. Bruce A. Tschantz for FEMA; and
- *The NWS Simplified Dam Break-Flood Forecasting Model*, Johnathan M. Wetmore and Danny L. Fread for FEMA.

FEMA has distributed over 20,000 copies of these Guidelines and materials to Federal, State and local dam safety officials as well as to members of the interested public.

During Fiscal Year 1986, ICODS and the Interagency Committee on Seismic Safety in Construction (ICSSC) established a formal liaison member to ensure appropriate exchange of information on topics of mutual interest.

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DIRECTORY

To obtain information on agency earthquake program activities, write or call:

Office	Name	Telephone
PRINCIPAL AGENCIES		
FEDERAL EMERGENCY MANAGEMENT AGENCY **500 C Street, S.W.** **Washington, D.C. 20472**		
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